BIOLOGY OF ANIMALS

VOLUME II

Text Book for Degree Students

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TO

OUR TEACHERS

WHO

TAUGHT US ZOOLOGY

Arup

Simananda

Banku

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Foreword

Sivatosh Mookerjee

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The writing up of a viable text-book is not as easy as it appears to be. Without being endowed with a natural sense of communication, clarity of exposition and certain degree of originality in organizing the material, the attempt to write a text would be a costly misadventure. The prospective writer must consciously control the osmotic gradient of fresh knowledge flowing into the pool of the existing one. The process of science is revealed in its unceasing progress; this means that the horizon of knowledge is continuously receding. The greatest obligation of a text-book writer is to remain alive to this fact and to minimize the gap by constant vigilance. Texts, written once cannot be perpetuated indefinitely. Texts are not intended to enslave the mind but to prepare it for more knowledgeable things hidden beyond the present contemplated boundaries. Its purpose is to arouse a sense of aptness for the subject concerned and to embolden curiosity for its material contents, in order to lead the way to the further progress. The purpose of a book lies in the mental preparedness for creating a new sense of dedication for the unknown.

To attempt now to write a text in Zoology for the Degree Course would be a matter of great adventure because modern Zoology has undergone a radical ecdysis and has emerged out into a new conceptual entity, both in contents and implications. Zoology is no longer a mere plethora of disjointed morphological descriptions. It is now a field of coherently integrated and biochemically analysable entity. Biological diversities have become resolved into a common theme of endless activity of the wonder molecule of DNA. Throughout the new vista of Zoology, causal interpretations of functional dynamism, adaptiveness in time, exploration of new ecological niches, biometry of forms have firmly been established.

The writers of the present volumes were my close collaborators in research. The image of modern biology is clearly inscribed in their minds. It is heartening to see that they have been able to assemble the main ingredients of the science of Zoology in a most coherent way and organised their material into a principle oriented discourse. Our syllabi, in most of the Universities, even to-day suffer from serious limitations. Often the contemporary outlook of Biology is not fully reflected in our curricula. However, within the available framework of the present day curricula, the authors have done their best to convey the message of modern Zoology. I have no doubt that the present volumes will generate impact on the modernization of the subject which we have cherished so much and for so long.

Sivatosh Mookerjee

Preface

We have decided to write a book on Zoology which would reflect the contemporary outlook of the subject and at the same time, would cover the syllabi of most Indian Universities. Our prime objective would be to see that the book helps the student to learn the subject. We expect the student to be a true literate in Zoology. They should be in a position to use their knowledge and training in their daily life and vocation. It is hoped that instead of mere cramming of the 'product' parts of the subject, the students will learn the 'process' involved in it. Such training would develop in their mind a sense of love and appreciation about the subject.

The above-mentioned paragraph was written before the writing of the manuscript. It speaks about our desired objectives. In order to attain it we have selected the most important theme of today's biology—*unity and diversity in living organisms*. As it is a book on Zoology, we have restricted ourselves only to the animals. The book begins with the idea of 'unity', the understanding of which can only help the reader to realise the guiding principles involved in the production and maintenance of the enormous array of 'diversity'. In the first volume, unity in the living world and non-chordate animals as the examples of diversity are included. The second volume has been devoted to the examples of chordates. The third volume will include the biological principles like development, heredity, ecology, adaptation, evolution and history of Zoology.

To satisfy the requirements of the Universities, the part dealing with the examples of diversities has become unusually longer. It is hoped that the readers of this book would find that the underlying principles of Zoology are more vital than the descriptive legends of animals. While presenting the facts we have taken this into consideration that figures become integral part of the text. Two types of illustrations have been used—some are of more artistic value while the others are line drawings for the easy understanding of the students. As far as practicable, Indian examples have been described and the works of Indian scientists have been incorporated.

We have no hesitation to admit that in spite of our best effort, we have not been able to reach our desired objectives. Repeatedly we found that it is impossible to reflect the 'contemporary outlook of the subject' in the frame work set for "the requirements of syllabi of our universities".

It is rather an unfortunate truth that even after the criticism of Kothari Commission, most Universities of our country have failed to implement a syllabus which would reflect the contemporary outlook of knowledge. We sincerely appeal to the teachers to come forward to convince their Universities to make the curriculum of Zoology not only modern but also more useful and meaningful. An ideal curriculum includes both the syllabus and the methods of its implementation. Both are interdependent and to make the curriculum successful it is necessary to consider both very carefully. It is needless to emphasize that the present method of teaching requires a change. A student of Zoology must learn the subject as a scientist. It is necessary to see that teaching of Zoology creates in the mind of the student a sense of enthusiasm and inquisitiveness. How can this goal be achieved? Which one will be best effective—enquiry approach or classical lecture-type method or both. The final answer can come only from the teachers who are involved in it. The authors of this book only want to assure that if something in this direction is done they will be glad to recast the entire content.

We are fortunate that in the preparation of this book we enjoyed the help and counsel of a large number of very competent persons. The acknowledgement of their names does not necessarily mean that they have approved everything in our final manuscript. We are grateful to them for their keen interest, untiring labour and critical but friendly co-operation, which have definitely put this book into a presentable shape.

We are specially thankful to Professor Sivatosh Mookerjee, F.N.A., (formerly, Head of the Department of Zoology, Presidency College, Calcutta and now at Jawaharlal Nehru University, New Delhi), for the genuine interest that he has kindly shown towards this book. Professor Mookerjee, who among a few others, was primarily responsible for bringing in the era of modern biology in the country, helped us many a times with his creative ingenuity during the various phases of gestation of the book. He was too kind to extend all the facilities of his laboratory to us. With deep respect we acknowledge the apt and excellent foreword that he has written for this book.

We shall be glad to acknowledge all comments, suggestions and corrections from the learned teachers and enthusiastic students. As this is the only way to improve the book further, we will give due honour to them.

Last but not the least, we appreciate the courage of Sri J. N. Sen of New Central Book Agency for entrusting upon a comparatively younger group of people to write the book on Zoology in their series of Biological Sciences. We are happy in being able to fulfil the responsibility assigned to us and that too, in much ahead of the stipulated time.

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Vol. II

(Chordates)

Vol. III (In Press)

(Evolution, Genetics, Ecology, Adaptation, Embryology and History of Zoology)

BIOLOGY OF ANIMALS

Life is a peculiar state of existence, so much different from non-life. Only the plants and animals can experience such a state, leaving aside still smaller forms known as viruses. There are bewildering forms of plants and animals probably with all imaginable differences in size and shape. This system of biological diversity can conveniently be harnessed into another pattern of unity—a unity in the ultimate similar chemical make up of all forms constituted by protoplasm. Protoplasm is a peculiar amalgam of different chemical recipes, fortified by a system of self-maintaining equilibrium.

Unity and diversity are the two facets of the bundle of life. Understanding of the mechanism involved in the form and function of life constitutes the subject matter of modern life science. Modern biology thus begs the assistance of such disciplines like physics, chemistry, mathematics, to give their hands for the ultimate solution of the life process.

Zoology, the subject matter of this book, is that branch of biology, which deals with the science of animal life.

DIVERSE MANIFESTATION OF LIFE THROUGH ANIMALS (Contd.)

CHAPTER 1

Phylum Chordata

The phylum Chordata is a vast group which includes diverse animals ranging from the *Balanoglossus* to Man (Fig. 1.1). A few characteristics like the Notochord, Dorsal tubular nerve cord and Pharyngeal gill-slits unite these diverse animals under a common phylum. They differ from the invertebrates significantly by the position of the nerve cord. The invertebrates possess a ventral nerve cord below the alimentary canal, while a dorsal nerve cord above the gut is the diagnostic character of the chordates. The phylum Chordata is of special interest to us, because we, the human beings are also included within the group.

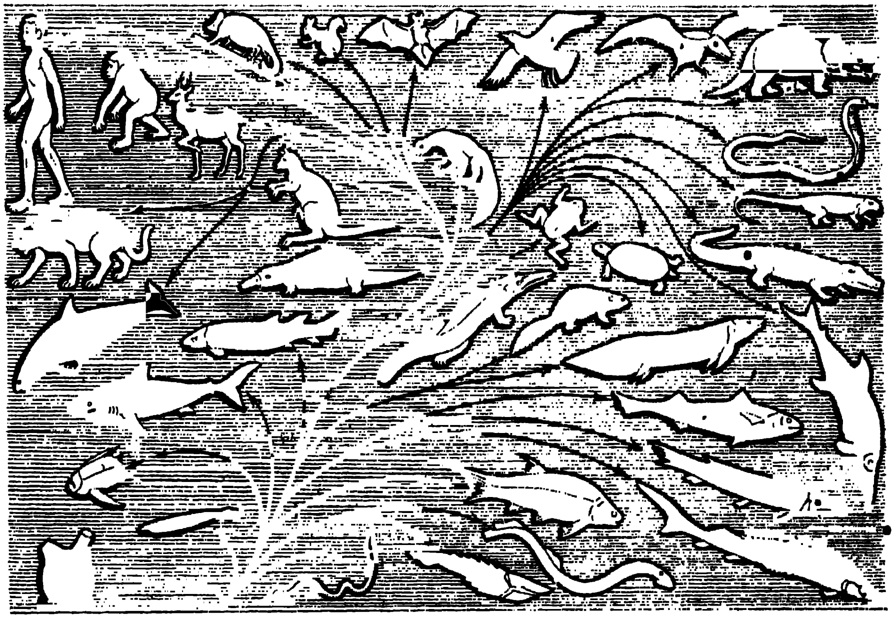


Fig. 1.1. Diversification of the chordates.

IMPORTANT FEATURES

The members of the phylum Chordata possess many features in common. The most important features are: (1) the Notochord, (2) the Dorsal Tubular Nerve Cord and (3) the Pharyngeal Gill-slits (Fig. 1.2). These three characteristics are unique for the phylum. Existence of such common structures is interpreted as a result of inheritance from a common ancestry. Besides these three structures, there are a few other characteristics which have less diagnostic value.

Notochord or Chorda Dorsalis

The notochord is the prime identifying structure of the chordates and the group derives its name from it. It is a rod-like elastic structure situated just above the alimentary canal and immediately beneath the dorsal tubular nerve cord. The notochord is composed of special type of vacuolated *notochordal cells* (Fig. 1.3) and remains covered over by one or two connective tissue coverings called the *notochordal sheath*. The notochord in the invertebrate chordates originates from the embryonic

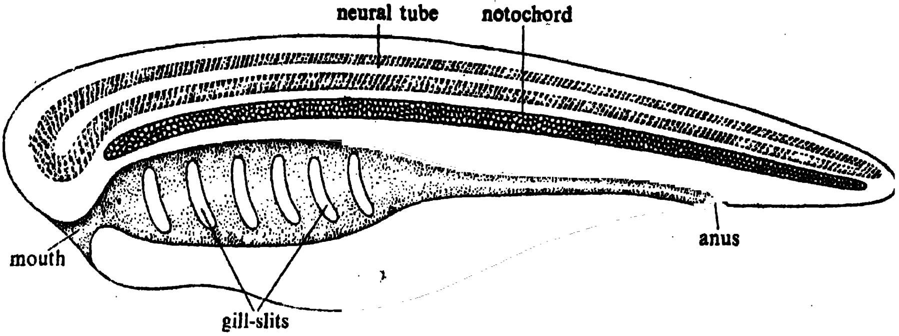


Fig. 1.2. Diagrammatic view of a chordate showing the three unique features of the chordate organisation (after Torrey).

endoderm, whereas, in the vertebrates it is a mesodermal derivative. The notochord may persist even in the adult invertebrate chordates, but in vertebrates it is either partially or wholly replaced by the vertebral column.

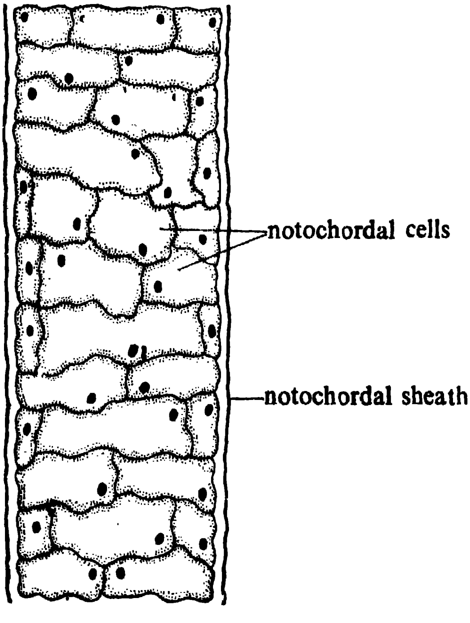


Fig. 1.3. Longitudinal section through the notochord of developing chick (after Mookerjee).

Dorsal Tubular Nerve Cord

In the chordates, a single dorsal tubular nerve cord extends along the anteroposterior axis of the body. It is located just above the notochord (Fig 1.4). This nerve cord originates from the embryonic dorsal ectoderm. It develops as an oval dorsal plate called the *neural* or *medullary plate*. The neural plate is formed as a result of assemblage of neural cells. The neural plate subsequently transforms into a *neural* or *medullary groove* due to the lateral pressure exerted by the surrounding nonneural tissue. The dorsal lips of the neural groove become fused with each other and a *neural tube* is formed. The cavity of the neural tube is called *neurocoel*. In the invertebrate chordates the dorsal tubular nerve cord remains almost unchanged, but in the vertebrates the anterior region of the nerve cord becomes specialised into the brain and the remaining part is modified into the spinal cord.

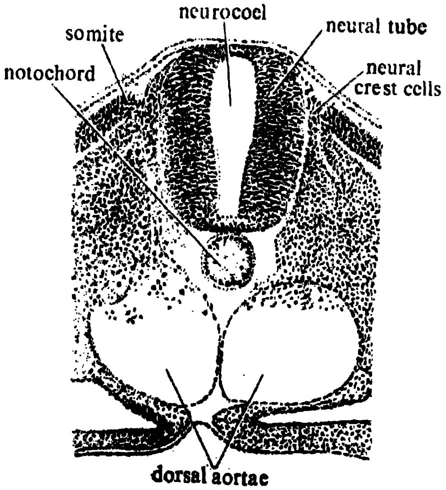


Fig. 1.4. Transverse section of the developing chick (passing through trunk region) showing the relative position of neural tube.

Pharyngeal gill-slits

The gill-slits have many alternative names, such as the pharyngeal or branchial clefts, visceral clefts, visceral or branchial pouches. In the majority of the primary aquatic chordates, the pharyngeal wall is perforated by gill-slits which are meant for the exit of the water current from the pharyngeal cavity to the outside. In the majority of such forms the respiratory organs (gills) are lodged in the gill-chamber. Exchange of gases takes place during the transit of the water current that passes through the mouth and goes out through the gill-slits. The gill-slits, as such, are persistant in invertebrate chordates, fishes, amphibian larvae and in the neotenic adult amphibians. But the transition from the aquatic environment to the land life has changed the nature of the gill-slits. The gill-slits lose their importance due to the acquisition of pulmonary respiration. The respiratory function of the gill-slits is taken up by the lungs, the respiratory organs of the land chordates. The initial stages of gill-slits formation are clearly seen in the embryos of the land chordates (Fig. 1.5). In the adults, these structures become transformed into other organs, specially the endocrine systems.

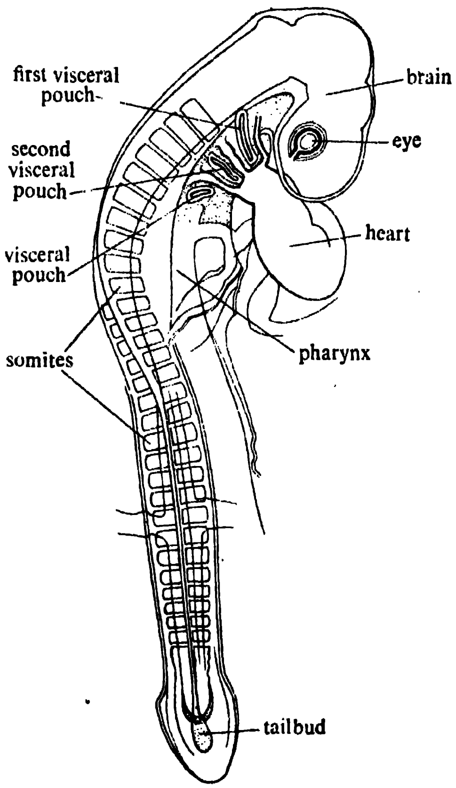


Fig. 1.5. A developing chick embryo of 30 somite stage. Note the formation of visceral pouches or gill-slits.

The gill-slits are developed as a result of subsequent fusion of the inpouchings of the body ectoderm with the corresponding outpouchings of the pharyngeal endoderm. Initially both the inpouchings and the outpouchings meet with each others and then the regions of union break through to form continuous passages between the pharyngeal cavity and exterior. The number of the gill-slits varies considerably in different chordates. *Cephalodiscus* bears only one pair of gill-slits whereas *Branchiostoma* possesses about two hundred.

THE CHORDATE FEATURES SHARED BY THE INVERTEBRATES

Besides the three unique features of the chordates, there are many characteristics which are also present in many higher invertebrates. The significance of the structural similarities are very difficult to interprete from the phylogenetic point of view. However, it may be suggested that the chordates as a group evolved from some higher groups of invertebrates and hence the structural resemblances are due to remote common ancestry.

Bilateral symmetry. Both the chordates and most of the invertebrates, like annelids, arthropods etc., exhibit distinct bilateral symmetry.

Axiate organisation. All the chordates have a distinct polar axis. The anterior end is marked by the presence of head and the posterior end is characterised mostly by the tail. The axis extending from the head to the tail end is regarded as the antero-posterior axis. The anteroposterior axis of the chordates corresponds to that of most of the higher invertebrates. The axiate organisation is not strictly homologous, because many fundamental differences exist between the two groups.

Triploblastic condition. All animals above the coelenterates, have a third germ layer besides the ectoderm and endoderm. This third layer is known as the mesoderm. Although the embryonic formation of the mesoderm is different in invertebrates, but the same is similarly formed in chordates, echinoderms, brachiopods, chaetognaths and in other enterocoelous forms. The triploblastic condition added more weight to the phylogenetic relationship of the chordates with the invertebrates.

Metamerism. Segmental organisation is characteristic for most of the invertebrates and the chordates. In annelids and arthropods, segmentation is well-marked both internally as well as externally, but in chordates the external segmentation is not seen. The segmental arrangement of the body-wall musculature is prominent in chordates.

OUTLINE CLASSIFICATION

Like many other phyla, the taxonomical subdivisions of the phylum Chordata is a problematic issue. Diverse opinions exist on this particular aspect. However, a compromise scheme is described below. It is largely based on the classificatory scheme adopted by Parker and Haswell.

The PHYLUM CHORDATA is divided into four subphyla. The subphyla are:

Subphylum I. CEPHALOCHORDATA OR ACRANIA

Subphylum II. HEMICHORDATA OR ADELOCHORDATA OR STOMOCHORDATA

Subphylum III. UROCHORDATA OR TUNICATA

Subphylum IV. VERTEBRATA OR CRANIATA

The subphylum Cephalochordata has no class under it. This subphylum is represented by two genera. But the subphylum Hemichordata includes three classes. The classes are: (A) Enteropneusta, (B) Pterobranchia and (C) Planctosphaeroidea. The subphylum Urochordata is subdivided into three classes: (A) Ascidiacea, (B) Thaliacea and (C) Larvacea or Appendicularia. The subphylum Vertebrata is the largest group amongst the chordates. The Vertebrata is divided into two superclasses: AGNATHA or MONORHINA and GNATHOSTOMATA or AMPHIRHINA.

The superclass Agnatha includes two classes:

CLASS 1. **Ostracodermi**
CLASS 2. **Cyclostomata**

The superclass Gnathostomata comprises of seven classes:

CLASS 1. **Placodermi**
CLASS 2. **Chondrichthyes** or **Elasmobranchii**
CLASS 3. **Osteichthyes**
CLASS 4. **Amphibia**
CLASS 5. **Reptilia**
CLASS 6. **Aves**
CLASS 7. **Mammalia**

SUMMARY

1. The phylum Chordata includes a large number of diverse animals ranging from the *Balanoglossus* to Man.

2. The members of the phylum possess many diagnostic features, of which the notochord, dorsal tubular nerve cord and gill-slits are the most important ones.

3. Other characteristics, like bilateral symmetry, axiate organisation, coelom, segmentation and triploblastic condition are less important because these features are also present in many invertebrates.

4. Classification of the phylum Chordata into different smaller groups is a complicated issue. However, the phylum is conveniently divided into four subphyla—CEPHALOCHORDATA, HEMICHORDATA, UROCHORDATA AND VERTEBRATA. *Branchiostoma*, *Balanoglossus*, *Ciona*, *Petromyzon*, *Scoliodon*, *Lates*, *Bufo*, *Calotes*, *Columba* and *Cavia* are some of the examples of the phylum Chordata.

Phylum Chordata—Invertebrate Chordates

The animals with backbone constitute the major subdivision of the phylum Chordata. The rest of the chordates, namely the hemichordates, urochordates and cephalochordates are neither vertebrates nor invertebrates, but form a sort of bridge between the two groups. These peculiar creatures are collectively called the Invertebrate chordates or Protochordates. They differ from the vertebrates mainly by lacking the vertebral column and the skull. But all other basic chordate features are present in these forms. The invertebrate chordates are mostly sedentary animals in adult stage and take the resort of ciliary feeding to compensate the purpose of locomotion (Fig. 2.1).

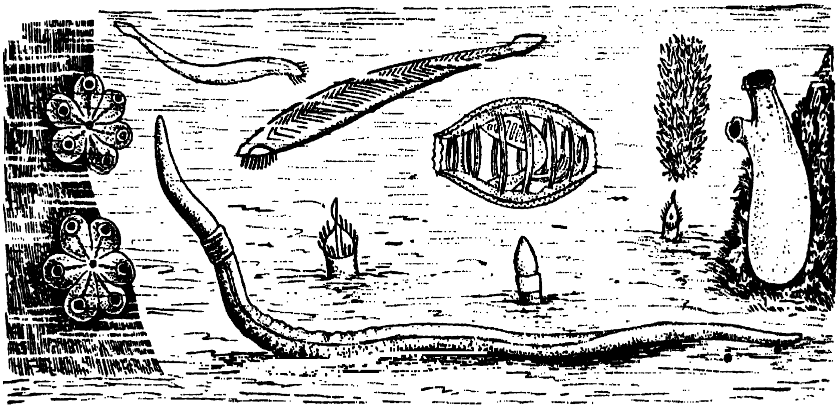


Fig. 2.1. A few invertebrate chordates in their usual habitats.

SUBPHYLUM CEPHALOCHORDATA (= ACRANIA)

The invertebrate chordates form a heterogeneous group of animals which show structural evolution from simple to complex. Of all the invertebrate chordates known so far, the subphylum Cephalochordata is described as an introductory group, because all the chordate features are well-illustrated in their adult forms. This group represents the living theoretical picture of a typical chordate.

IMPORTANT FEATURES

The Subphylum Cephalochordata derives its name from the characteristic that the notochord extends far forward beyond the brain, a feature not found in other chordates. This subphylum includes a very small number of marine animals represented by two genera only.

OUTLINE CLASSIFICATION

Two genera, *Branchiostoma* and *Asymmetron*, are included under the subphylum Cephalochordata. About eight species are recognised under the genus *Branchiostoma* and the genus *Asymmetron* includes six species. Both the genera have a generalised structural organisation, but *Asymmetron* differs from *Branchiostoma* in having gonads situated only on the right side of the body.

EXAMPLE OF CEPHALOCHORDATA—

BRANCHIOSTOMA (AMPHIOXUS)

The most extensively studied cephalochordate, *Branchiostoma* (*Amphioxus*) *lanceolatum* is selected as a type specimen to give an idea of cephalochordate organisation. It has almost a cosmopolitan distribution and extends all round the seas of the world.

HABIT AND HABITAT

Branchiostoma is a sedentary animal, although it can swim actively in water. It can swim vertically in water. It burrows in the sand, but remains always at a small depth. It keeps the anterior end of the body projected above the sandy bed to maintain a constant water current passing in through

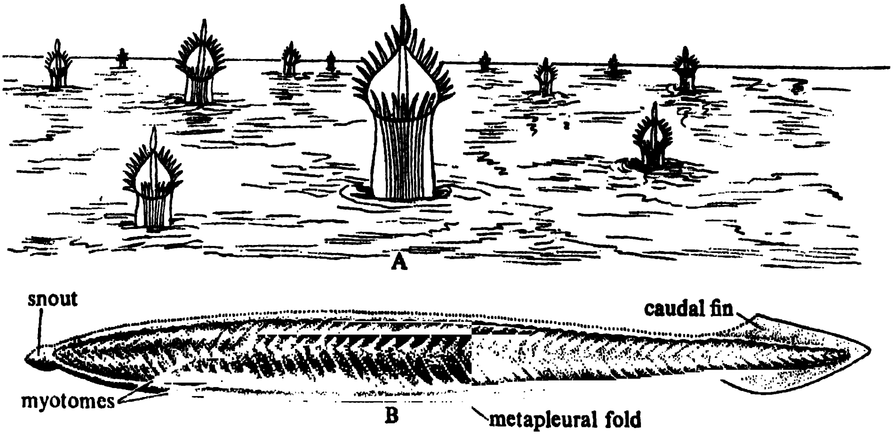


Fig. 2.2. A. Showing the anterior ends of a number of *Branchiostoma*. Note that the animals lie buried in sandy bottom with the anterior part of the body protruding out to maintain the feeding and respiratory currents. B. A diagrammatic view of a *Branchiostoma*.

the mouth and expelled through the atriopore (Fig. 2.2A). Branchiostoma feeds on micro-organisms brought into the pharyngeal cavity together with the respiratory water current. It exhibits a typical case of ciliary mode of feeding.

EXTERNAL STRUCTURES

Branchiostoma is a small lancet-shaped creature with sharply pointed anterior and posterior ends (Fig. 2.2B). The length of the animal varies from 5–8 cm. The body is elongated and flattened from side to side. The body is distinguishable into the *body proper* and a definite postanal *tail*. The head is not recognisable from the body and is marked by *buccal cirri* around the *oral hood*. The *mouth* is kept hidden within the oral hood. The *anus* is situated on the left side of the ventral fin and at a short distance from the posterior end of the body. The *atrium* opens to the exterior through a round *atriopore* located immediately to the anterior end of the ventral fin. The anterior portion of the body is roughly triangular in outline while the posterior part behind the atriopore is more or less oval in cross section. On the lateral sides of the body proper there are numerous *gill-slits* which remain partly covered by the lateral folds of the body. As a result the gill-slits are not usually seen from outside.

The body is provided with a median longitudinal fold called the *dorsal fin* which extends along the whole of the dorsal side. The dorsal fin is continued round the posterior end of the tail and proceeds forward on the ventral side up to the atriopore as the *ventral fin*. The dorsal and ventral fins are supported by a series of connective tissue *fin-ray boxes*. At the posterior end of the tail there is an expanded *caudal fin*. Running along the ventrolateral sides of the anterior two-third of the body there are two longitudinal *metapleural folds*. These metapleural folds extend between the oral hood and the atriopore. The paired fins are absent but the metapleural folds can be homologised with lateral fin folds, from which the vertebrate limbs might have possibly emerged out.

BODY WALL

The *epidermis* is composed of a single layer of cells. The epithelial cells are of columnar types (Fig. 2.3). These cells are ciliated in the early stage and in the adult

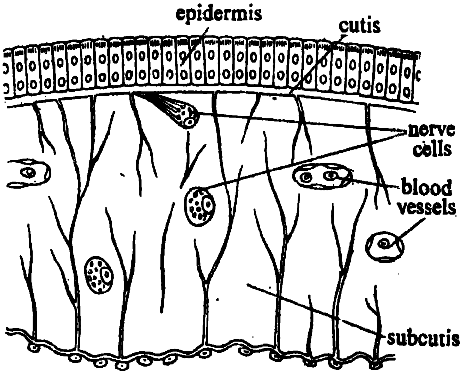


Fig. 2.3. Sectional view of the skin of *Branchiostoma* (after Young).

the outer margin of the cells become cuticularised. The chemical nature of the cuticle is not known. The epithelial layer contains cells with sensory hairs (*receptor cells*), but the gland cells and pigment cells are absent. Immediately beneath the epidermis, there are two layers—*cutis* and *subcutis*. Both these layers are secreted by some scatteredly distributed wandering cells akin to the fibroblasts of the vertebrates. The cutis is made up of fibres and the subcutis has a gelatinous matrix containing fibres. A system of canals traverse through both the cutis and subcutis.

Beneath the subcutis lies the characteristic muscle layer of Branchiostoma. The mesodermal layer applied to the gut (*splanchnopleure*) becomes greatly thickened near the notochord to transform into the *myotomes*. Besides the myotomes, other muscles also develop from the splanchnopleure and *somatopleure* (the mesodermal layer applied to the body-wall). The myotomes are blocks of striated muscle-fibres extending through the entire length of the body. The myotomes are separated from one another by dense connective tissue called the *myocommas*. The myocommas are 'V'-shaped and the pointed end of the 'V' is directed towards the anterior end (Fig. 2.2). Although the myocommas are 'V'-shaped, the muscle-fibres composing the myotomes run straight, i.e., arranged longitudinally. Each muscle fibre is attached to two successive myocommas. The myotomes are so arranged that the body can be twisted sidewise with a considerable rapidity. The myotomes on the two sides of the body alternate with one another. Such an arrangement of myotomes help lateral undulation of the body during locomotion. There are about 60 pairs of myotomes in Branchiostoma.

The most significant point to note in the muscular system of Branchiostoma is the great thickness of the musculature of the dorsal body wall. In invertebrates the muscle layer is of almost uniform thickness surrounding the coelom.

SUPPORTING STRUCTURES

The notochord extends from the very end of the head to the tip of the tail. Such anterior prolongation of the notochord beyond the brain is associated with its burrowing habit. This chord is situated on the middrosal line of the alimentary canal. It is composed of a series of flat plates arranged along the transverse plane of the body. Two kinds of plates alternate with each other, one is fibrous in nature and the other is homogeneous. The plates are enveloped by an outer fibrous and an inner elastic notochordal sheath. Each plate is derived from a single cell which becomes highly vacuolated and the nucleus is pushed to one side. Surrounding the notochordal sheath there is a noncellular gelatinous layer containing few fibres.

The other supporting structures include the gill-rods supporting the gill-bars, the skeletal oral ring supporting the oral hood and cirri and the fin-ray boxes supporting the fins (Fig. 2.4A).

LOCOMOTION

Branchiostoma is a sluggish animal by nature and it occasionally swims freely in water by the contraction of the longitudinal muscle-fibres of the myotomes. Contraction of the myotomes causes the transverse motion of the body at different angles in such a fashion that the animal can move forward. All the myotomes contract rhythmically along the anteroposterior direction, i.e., a myotome contracts after that in front of it. During forward propulsion the myotomes contract to produce waves of contraction from anterior to the posterior side through the water. The myotomes are located on the lateral side of the notochord which forms the supporting structure. The function of the notochord is to prevent shortening of the body length when the muscle-fibres of the myotomes contract. The elasticity of the notochord helps to make the contraction of the body more efficiently. The notochord acts as the lever upon which the myotomes work. The myotomes have no direct connection with the notochord, but the myocommas are attached with the notochordal sheath.

Branchiostoma cannot move very fast in water and the elaborate fin-system as seen in fishes is absent. The caudal fin is feebly developed. It normally resists transverse movements of the body and can accelerate transverse movements in emergency.

TRANSVERSE SECTIONS OF THE BODY

The body proper of Branchiostoma is usually distinguished into the pharyngeal and intestinal regions. A transverse section passing through these regions show both similar and dissimilar features (Fig. 2.4C, D).

Similar features. *When a transverse* section is cut through any region of the body, the following structures are visible. The structures are: (1) The outer side of the body is lined by a single layered epidermis, with cutis and subcutis beneath the epidermis. (2) The portion between the *subcutis and the coelom is occupied by* blocks of muscle fibres called the myotomes. The myotomes are separated from one another by the myocommas. The myotomes are well-developed on the dorsolateral sides of the body. (3) A middorsal fin with supporting fin-ray box is present.

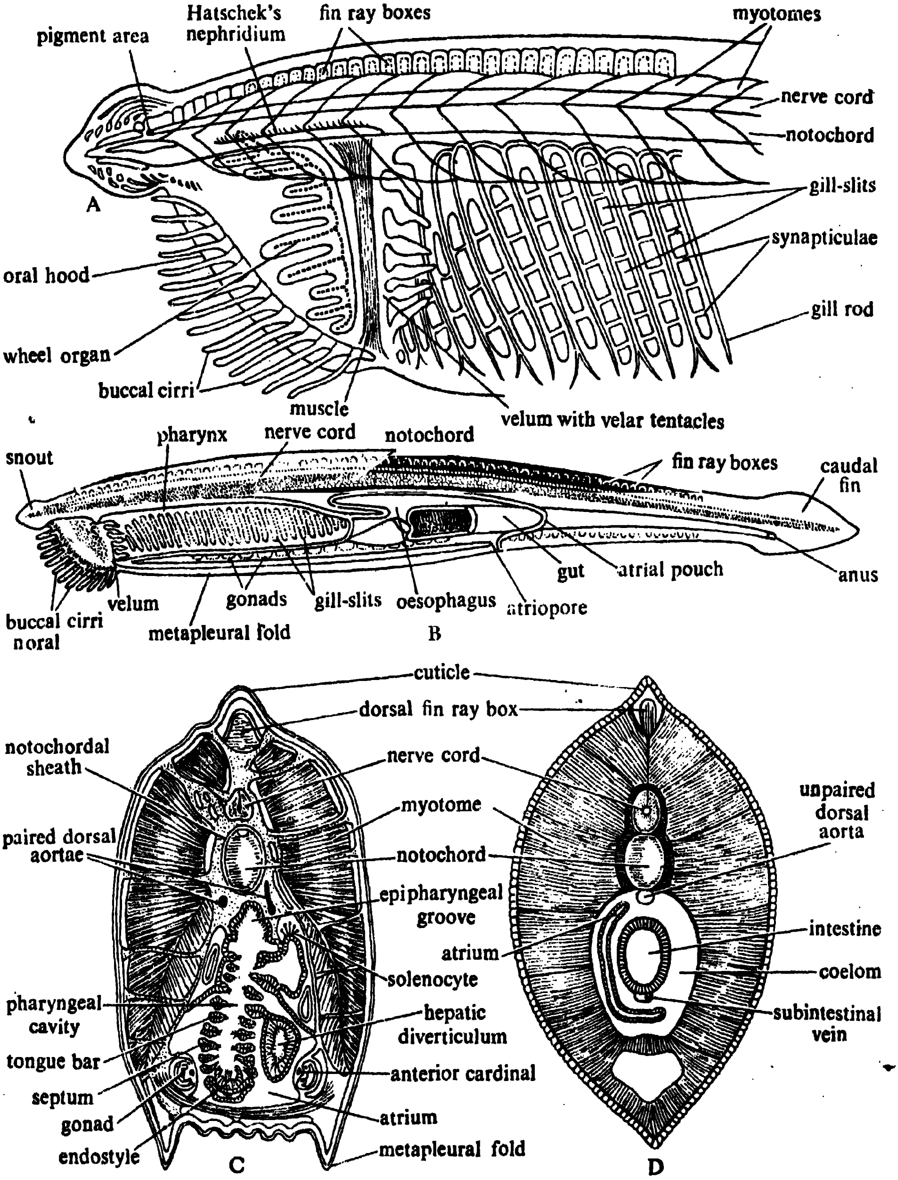

Hatschek's nephridium
fin ray boxes
pigment area
myotomes
nerve cord
notochord
A
gill-slits
synapticulae
oral hood
gill rod
wheel organ
buccal cirri
muscle
velum with velar tentacles
pharynx
nerve cord
notochord
snout
fin ray boxes
caudal fin
gut
atrial pouch
anus
velum
gonads
gill-slits
oesophagus
atriopore
buccal cirri
noral
metapleural fold
B
cuticle
dorsal fin ray box
notochordal sheath
nerve cord
myotome
unpaired dorsal aorta
paired dorsal aortae
notochord
epipharyngeal groove
atrium
intestine
coelom
solenocyte
pharyngeal cavity
hepatic diverticulum
subintestinal vein
tongue bar
anterior cardinal
septum
gonad
atrium
endostyle
metapleural fold
C
D

Fig. 2.4. Diagrammatic sectional views of *Branchiostoma*.
A. Longitudinal section through the anterior end of the body in a greatly enlarged view (after Jollie).
B. Longitudinal section through the entire body showing the gross anatomical construction (after Jollie).
C. Transverse section through the pharyngeal region (after Jollie).
D. Transverse section through the intestinal region (after Parker and Haswell).

(4) Immediately above the alimentary canal there lies the notochord which thus occupies middorsal position. (5) A hollow nerve cord is present just above the notochord.

Dissimilar features. Besides the common features, there are specific differences between the sections of the pharyngeal and intestinal regions. The differences are tabulated in Table Chordata-I.

TABLE—CHORDATA-I

COMPARATIVE ACCOUNT OF THE TRANSVERSE SECTION THROUGH PHARYNGEAL AND INTESTINAL REGIONS OF BRANCHIOSTOMA

Structures	Pharyngeal region	Intestinal region
Shape of the body	More or less triangular in outline.	Oval in outline
2. Ventral fin	Two metapleural folds are present, one on each ventrolateral side of the body. Supporting fin-ray box is absent.	Single midventral fin with supporting fin-ray box is present.
3. Dorsal aorta	Two dorsal aortae, one on each dorsolateral side of pharynx are present.	Single dorsal aorta is present on the middorsal side of the intestine.
4. Alimentary canal	Pharynx with many gill-bars and gill-slits are visible in a transverse section. This is because of the fact that the gill-bars and gill-slits remain diagonally to the body. The endostyle and the epipharyngeal groove are present on the midventral and middorsal sides of the pharynx respectively.	Simple circular intestine with the gut content is seen.

DIGESTIVE AND RESPIRATORY SYSTEMS

In Branchiostoma the digestive and the respiratory systems are intimately associated with one another. For this purpose, the *pharynx* is a very elaborate structure which occupies more than half of the total surface area of the body. The food particles are filtered from the respiratory water current that passes in the mouth and goes out through the atriopore via the gill-slits. The cilia present in the pharyngeal cavity play the most important role in capturing the food.

A large median aperture is situated just below the pointed tip of the anterior end. This aperture is surrounded by a frill-like membrane called the *oral hood* (see Fig. 2.4A). The membranous lateral and ventral margins of the oral hood are fringed with *buccal cirri*. The buccal cirri are beset with *sensory papillae*. The oral hood and the buccal cirri are supported by skeletal rods. During the inflow of water current, the buccal cirri form a sieve to prevent the entry of large food particles. The oral hood encloses a cavity called the *vestibule*. The *mouth* is a small rounded aperture situated at the posterior end of the vestibule. The mouth is surrounded by a membrane called the *velum*. The velum is produced into slender *velar tentacles* and acts as a sphincter to open or close the mouth (see

Fig. 2.4 A, B). The lining of the vestibule produces a complicated ciliated tract called the *"wheel organ"* by Muller. The wheel organ produces a vortex of water to sweep the food matters into the mouth. There is a ciliated groove running along the roof of the vestibule named the *pit of Hatschek* (Fig. 2.5A). The left embryonic coelomic cavity of the head region becomes reduced to form the pit of Hatschek of the adult.

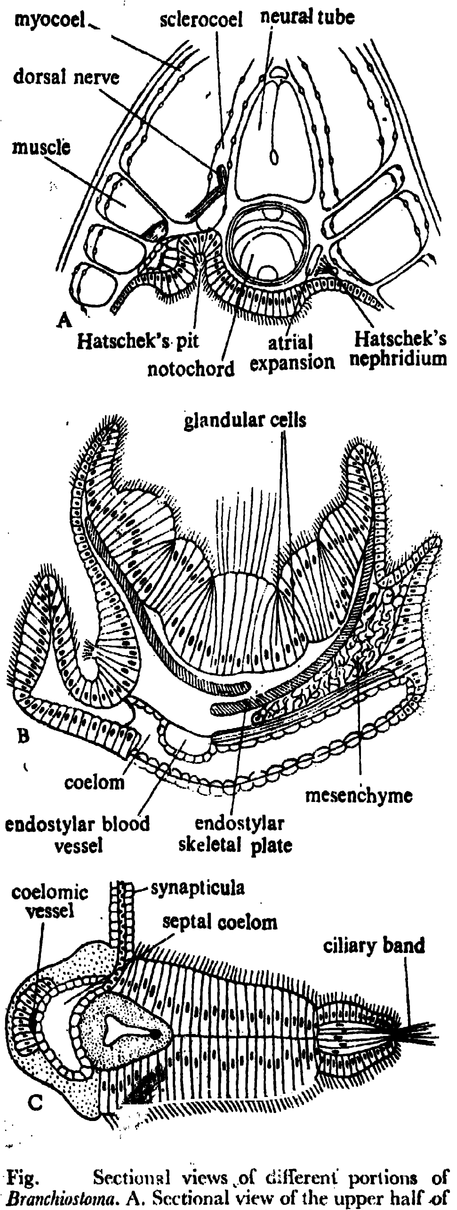


Fig. Sectional views of different portions of *Branchiostoma*. A. Sectional view of the upper half of the oral funnel. Note the position of Hatschek's pit, Hatschek's nephridium, etc. B. Transverse section through the floor of the pharynx showing the relationship of the endostyle with others. C. Transverse section of a single gill bar (after Jollie).

The mouth opens into a very large laterally compressed tube called the pharynx. The pharynx in Branchiostoma plays a dual role—the collection of food particles and the respiration. The lateral wall of the pharynx is perforated by obliquely arranged vertical slit-like apertures —the *gill-slits* (see Fig. 2.4B). The number of the gill-slits is about 200, but the slits increase far beyond the number of body segments. The gill-slits increase in number as the animal grows older. The gill-slits open into a special cavity, the atrium or peribranchial cavity which surrounds the pharynx on all sides except the dorsal. The atrium is closed anteriorly but opens to the exterior through the atriopore.

The gill-slits are separated from one another by the portion of the walls of the body and the pharynx. These portions are called the *gill-bars* or *branchial lamellae*, i.e., the gill-bars are actually the vertical portions of the main body wall and the pharyngeal wall. Such a portion of the gill-bar which encloses the coelom is called the *primary gill-bar.* With the advancement of age, each primary gill slit is divided into two by the downward growth of the *tongue bar.* These resultant gill-bars are named as the *secondary gill-bars* which lack coelom. The gill-bars are provided with cilia. The gill-bars contain supporting *gill-rods*. The gill-rods are of two types—the primary gill-rods and the secondary gill-rods. The terminal end of the primary gill-rod is forked and those of the secondary gill-rods are simple i.e., unforked. Depending on the presence of particular type of gill-rods, the gill-slits are also designated as the primary or secondary ones. The primary branchial lamellae are connected by transverse skeletal rods called the *synapticulae*.

The internal wall of the pharynx is ciliated. Several ciliated tracts are present inside the pharynx. An *endostyle* is present on the floor of the pharynx. The endostyle consists of a few tracts of ciliated cells alternating with mucus-secreting glandular bands (Fig. 2.5B). According to Barrington (1968), the endostyle becomes transformed into thyroid gland of vertebrates. He has observed the concentration of radioactive iodine in the glandular columns of the endostyle. The extract contains iodine and on administration accelerates the metamorphosis of Tadpole larva. (There is another median groove on the dorsal side of the pharyngeal cavity called the *epipharyngeal* or *hyperpharyngeal groove*. The epipharyngeal groove joins with the anterior end of the endostyle by *peripharyngeal ciliated tracts.*)

Behind the pharynx, the alimentary canal narrows at its posterior side into an *oesophagus* which opens into the *midgut*. The pharynx and oesophagus constitute the *foregut*. At the junction of the oesophagus and the midgut there is a large outpouching called the *hepatic diverticulum* or *midgut diverticulum* (Fig. 2.6A). This diverticulum extends forward on the right-hand side of the pharynx for about one-third of the length of the pharynx. It contains *zymogen cells* and produces digestive enzymes. The inner walls of the diverticulum, specially the dorsal and ventral walls are beset with large cilia. The posterior end of the midgut is specially ciliated and called the *ileocolon ring*. Behind the ileocolon ring the intestine proceeds backwards as a straight *hindgut* which opens through the *anus*.

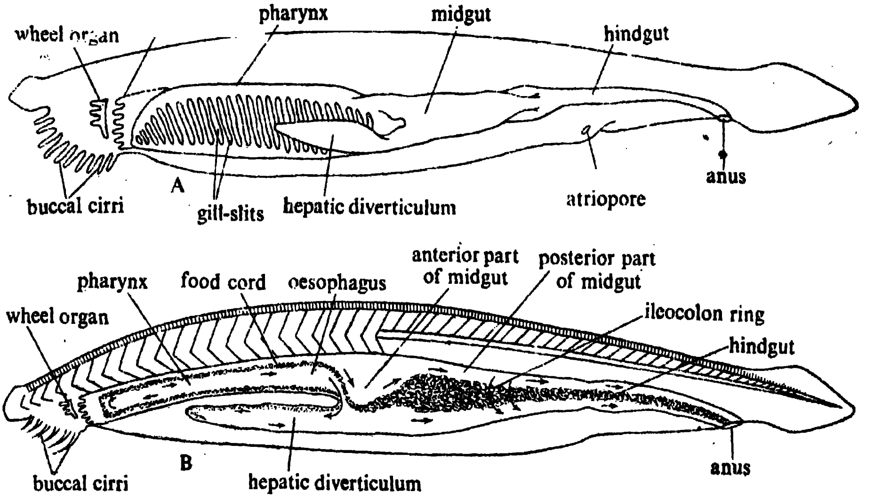


Fig. 2.6 A. Digestive system of *Branchiostoma*. B. Showing the schematic representation of the feeding current through the gut. The arrows indicate the direction of movement of food cord.

Mechanism of Feeding and Digestion

Branchiostoma is a microphagous animal which obtains the food by filtering the stream of water that enters the pharyngeal cavity. The wheel organ produces a vortex of water current which is drawn in towards the mouth. The buccal cirri become curved to form a seive to prevent the entry of large particles of food. The ingress of water into the pharyngeal cavity through the mouth is controlled by the velum. The pharynx plays the most important role in food collection. The major portion of the water passes out into the atrium through the gill-slits. The cilia present on the gill-bars beat to drive the water out into the atrium and thus facilitate the inflow of fresh water current through the mouth. The food particles are entangled by the sticky secretion of the mucus secreting cells of the endostyle. The cilia in the endostyle and gill-bars beat to produce an upward current to push the mucus entangled food particles towards the epipharyngeal groove. The cilia of the endostyle also beat to drive the food along the peripharyngeal ciliated tracts to the epipharyngeal groove. The food is pushed backwards by the backward beating of the cilia of the epipharyngeal groove (Fig. 2.6B). The secretion of the glandular cells of the endostyle transforms the boluses of mucus entangled food particles into a cord-like structure known as food cord.

The food cord from the pharynx passes through the oesophagus into the hepatic diverticulum and the midgut where this food cord is subjected to the action of digestive enzymes secreted by the hepatic diverticulum. The food cord from the hepatic diverticulum is pushed backwards by the cilia present in its cavity. The mucus-entangled food cord is rotated by the ciliary action in the ileo-colon ring.

The digestion in Branchiostoma is both intracellular as well as extracellular. The secretory cells of the hepatic diverticulum show phagocytosis, i.e., the cells are able to engulf the food particles from the food cord and digest the food as in Amoeba and Hydra. The phenomenon of phagocytosis is attested by the fact that the carmine particles, after injection into the diverticulum, are taken inside the cells. Extracellular digestion occurs inside the midgut. The digested food is absorbed in the hindgut and the undigested particles are expelled through the anus.

The controlling mechanism of the ciliary mode of feeding in Branchiostoma is not clearly known. The afferent and efferent nerve fibres in the atrium presumably play the important role in feeding. The rate of water current is largely controlled by the intensity of beating of cilia and also the degree of contraction or dilatation of the inhalant and exhalant apertures. The different receptors present on the velum and the atrium taste the nature of water current. If the water current contains any toxic substance, the atriopore is closed and the water is regurgitated by the sudden contraction of the *pterygial muscles* which form the floor of the atrium. Bone (1960) has shown that after the ingestion of sufficient food, the food collection is stopped until the food that has been taken in is digested.

Respiratory mechanism

The wall of the pharynx is highly vascular. The water current entering into the pharyngeal cavity brings fresh oxygen dissolved in water. The gill-bars contain blood vessels with many lateral branches. The blood circulates so close to the surface that these blood vessels are able to absorb oxygen and give off carbon dioxide very effectively.

CIRCULATORY SYSTEM

The circulatory system in Branchiostoma is well-developed (Fig. 2.7). The blood is colourless, i.e., it lacks any respiratory pigment. The blood is also devoid of cells and the blood vessels, except the dorsal aorta, are without any lining.

The blood from the different parts of the body is collected into a large sac called the *sinus venosus*. The sinus venosus is situated below the posterior end of the pharynx. From the sinus venosus a large median artery arises which extends forward below the pharynx. This artery is named as the *ventral aorta* or *truncus arteriosus* or *endostylar artery*. The ventral aorta gives the *branchial vessels* carrying blood to the gill-bars. The branchial vessel, at the base of each primary gill-bar dilates to form a tiny expansion called the *branchial bulb* or *bulbule* (pleural *bulbuli*). From the gill-bars the blood is collected by the paired *dorsal aortae*, situated one on each dorsolateral side of the pharynx. These paired aortae join posteriorly to form an unpaired *median dorsal aorta*. This dorsal aorta extends posteriorly up to the tip of the tail as the *caudal artery*. The paired dorsal aortae give small arterial vessels to the nephridia. These vessels form a net of minute vessels called the *nephric glomerular sinus*.

The paired and unpaired dorsal aorta have many branches which lead into the lacunae called the *myocoel* (the space between the myotomes and the body wall). The whole of the intestine and the hepatic diverticulum have extensive blood plexus. True capillary system is absent in Branchiostoma. The blood from the tail region

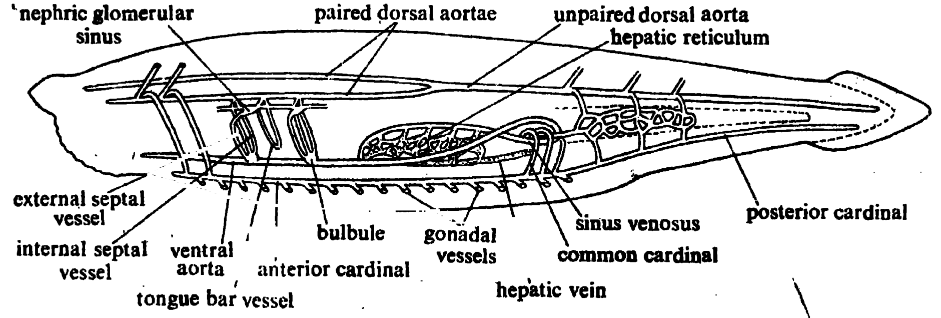


Fig. 2.7. Diagrammatic view of the circulatory system of *Branchiostoma*.

is collected by a *caudal vein*. It proceeds forward to join with the *subintestinal vein*. The subintestinal vein collects blood from the *intestinal plexus*. This vein runs into the hepatic diverticulum as the *hepatic vein* and from there the blood is carried to the sinus venosus. The blood from the ventrolateral sides of the body wall is collected by two pairs of *cardinal veins*—the *anterior cardinals* and the *posterior cardinals*. The anterior and posterior cardinals of each side unite to form a *common cardinal* or *ductus Cuvieri* which passes ventrally to join with the sinus venosus.

The sinus venosus, ventral vessel, branchial bulbs, nephric glomerulae and subintestinal vein are contractile. The rate of contraction is very slow and occurs once in two minutes. The phenomenon of contraction is irregular and is not controlled by any coordinated system. The course of circulation in Amphioxus is as follows. (1) The blood circulates from the posterior to the anterior end through the ventral vessel, subintestinal vein and the posterior cardinal veins. Whereas (2) the paired and unpaired dorsal aortae and the anterior cardinal veins drive blood from the anterior to the posterior direction.

EXCRETORY SYSTEM

The main excretory organs of the Branchiostoma are the NEPHRIDIA. The nephridia are situated above the pharynx. Each nephridium is a bent vesicular sac having one *horizontal* and one *vertical limbs*. The nephridia are segmentally arranged. Each sac corresponds to each primary gill-bar and opens by a *nephridiopore* to the atrium. A large number of elongated tubular *flame cells* or *solenocytes* open into the vesicle (Fig. 2.8A). Each solenocyte has a long tubular stalk with a tiny balloon-like cell-body at the terminal end. The cell-body gives off a *flagellum* through the hollow stalk which helps in eliminating the waste products (Fig. 2.8B). The solenocytes become associated with nephric glomerular sinus which separates the solenocytes from the coelomic epithelium. The excretion takes place through the wall of the solenocytes and passes down into the cavity of the vesicle through the tubular part. The nephridia are ectodermal in origin. The presence of nephridia in Branchiostoma is peculiar, because these structures are not present in any other chordate.

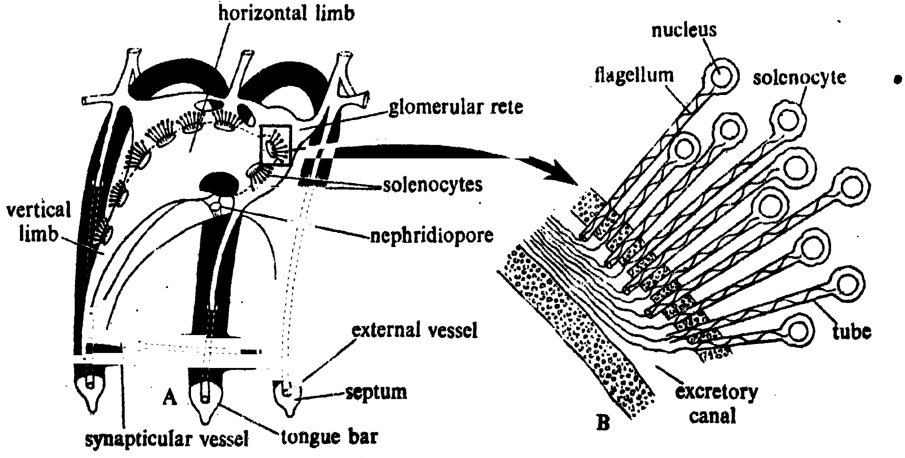


Fig. 2.8. Nephridial structures in *Branchiostoma*. A. Lateral view of a nephridium (after Jollie). B. Enlarged sectional view of a bunch of solenocytes.

NEPHRIDIUM OF HATSCHEK. Besides, the nephridia, a tube called the *nephridium of Hatschek* is regarded to be excretory in function. It arises from the mouth and proceeds forward to the right side of the notochord.

Miscellaneous excretory organs

BROWN FUNNELS. A pair of *brown funnels* is also claimed to play the excretory role. These are blind sac-like bodies of the anterior end of atrium and protrude into the epibranchial coelom. Although these are assigned to be excretory structures by many workers, these are possibly receptor organs.

ATRIAL WALL. Groups of cells in the atrial wall subserve the excretory function.

GONADS. Inside the gonads, particularly *in the testes, there are yellow masses containing* uric acid. These masses are expelled along with the gametes.

NERVOUS SYSTEM

The nervous system of Branchiostoma consists of a hollow *dorsal nerve cord* situated just above the notochord. The anterior part of the nerve tube is slightly dilated to form the brain and the posterior part remains as the *spinal cord*. The nerve tube gives *paired nerves* in each segment of the body. The paired nerves are the dorsal and ventral nerves which remain separate. The ventral nerve root lies opposite to the myotome and the dorsal nerve root passes out between the myotomes. The nerves are non-myelinated, i.e., the nerves are not ensheathed by a thick myelin sheath as seen in the nerves of vertebrates. The ventral root carries the motor fibres, but the dorsal root is mixed. It carries motor fibres for the non-myotomic muscles and sensory nerves for the segment.

At the anterior end of the nerve tube, the *neurocoel* ' becomes enlarged to form a *ventricle*. The first two anterior dorsal nerves emerge out from it, but the corresponding ventral nerves are lacking. These two nerves convey the impulses from the receptors of the oral hood and buccal cirri. An *infundibular organ* is present on the ventral wall of the ventricle (Fig. 2.9). It consists of tall cells with strong cilia. This organ gives origin to *Reissner's fibre* which proceeds posteriorly along the nerve tube. The Reissner's fibre is comparable to that of the vertebrates. The cells of the infundibular organ contain neurosecretory material as observed in the fibres of the vertebrate hypophysial organ. In the young stage, the ventricle opens through a *neuropore* which becomes closed in the adult. The region of the closure is marked by a depression called *Kolliker's pit*. The anterior end of the ventricle contains pigmented cells and sensory cells. These are regarded as photoreceptors. But the photoreceptive function of these cells has not yet been experimentally proved. The photosensory cells, present in the spinal cord are actually the photoreceptors. This is quite evident from the experiment conducted by Parker. A beam of light will initiate movements of Branchiostoma only when the light falls on the body, not when directed on the head.

The spinal cord has a narrow central lumen and has, like that of vertebrates, the orientation of "grey matter" and "white matter". The "grey matter", i.e., the cell layer is present surrounding the canal and the "white matter", i.e., the fibrous layer is situated on the outer side. Scattered in the spinal cord there are *photosensory cells* (eye-spots) enclosed by a cup of pigment granules, the *cells of 'Joseph'* and *Hesse* and the *giant cells of Rhodes* (Fig. 2.9). The cells of Hesse are distributed along the inner side of the tube along the entire length, whereas the cells of Joseph are present anterodorsally. The giant cells of Rhodes have many dendrites and one axon. The axon of the anterior giant cells proceeds backward and that of the posterior ones run forward. The giant cells are absent between 13–39 segments.

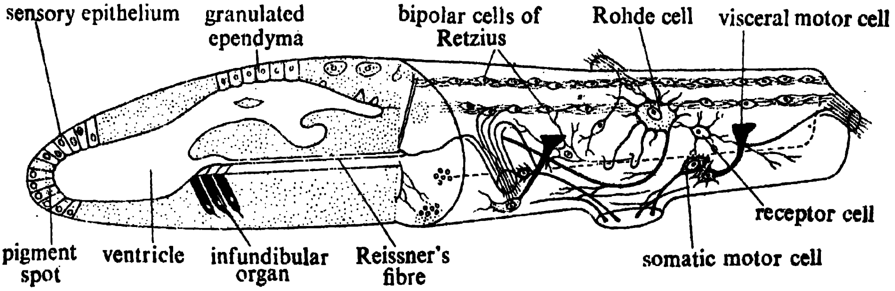


Fig. 2.9. Nervous system of adult *Branchiostoma*. The brain is sectioned longitudinally to show the details (after Young).

Branchiostoma lacks special sense organs. The receptors of the buccal cirri are responsible for the sense of touch. The velum contains chemoreceptors. The important sensory units are the photosensory cells scattered in the spinal cord. The function of the infundibular organ is not definitely known. It is probably a gravity or pressure receptor.

REPRODUCTIVE SYSTEM

The sexes are separate in Branchiostoma. The gonads are simple pouch-like segmental organs situated in the ventrolateral sides of the pharyngeal region between the 10th to 30th segments. The gonads proliferate from the mesodermal cells and the gametes develop from the walls of the gonads. It is claimed that each gonad develops from a single cell. The gonoducts are absent and the gametes are discharged into the atrium by dehiscence. From the atrium the gametes escape to the exterior through the atriopore along with the water current. Fertilization and development occur in sea water. The eggs are small but contain yolk.

DEVELOPMENT

The development of Branchiostoma is shown in Figure 2.10. The cleavage is holoblastic and the blastomeres are slightly unequal in size. The *blastomeres* arrange themselves to form a *blastula* enclosing a blastocoel. The roof of the blastula contains comparatively smaller blastomeres and the floor is composed of rather large cells. The gastrulation starts with the invagination of the larger cells to form the *archenteron*. The *blastopore* is persistent and transforms into the anus. The gastrula becomes covered with large cilia which help in the rotation of the embryo. Due to the invagination and enlargement of the archenteron the original blastocoel is obliterated and the gastrula becomes double-walled (Fig. 2.10H). The embryo now elongates along the antero-posterior axis and transforms into a *neurula stage*. The neurula stage is characterised by the presence of a neural tube which is formed by the unfolding of the dorsal ectoderm. At this time the innermost layer, i.e., the lining of the archenteron produces two lateral pouches, one on each dorsal side of it. These pouches are the source of future *mesoderm* and the cavities are that of the primordial *coeloms* (Fig. 2.10 I, J). The pouches become subsequently cut off from the archenteron. The coelom, in Branchiostoma, is enterocoelous in origin. The notochord develops from the dorsal wall of the archenteron.

The overlying layer of the embryo is the embryonic ectoderm which develops into the skin and the neural tube. The archen-

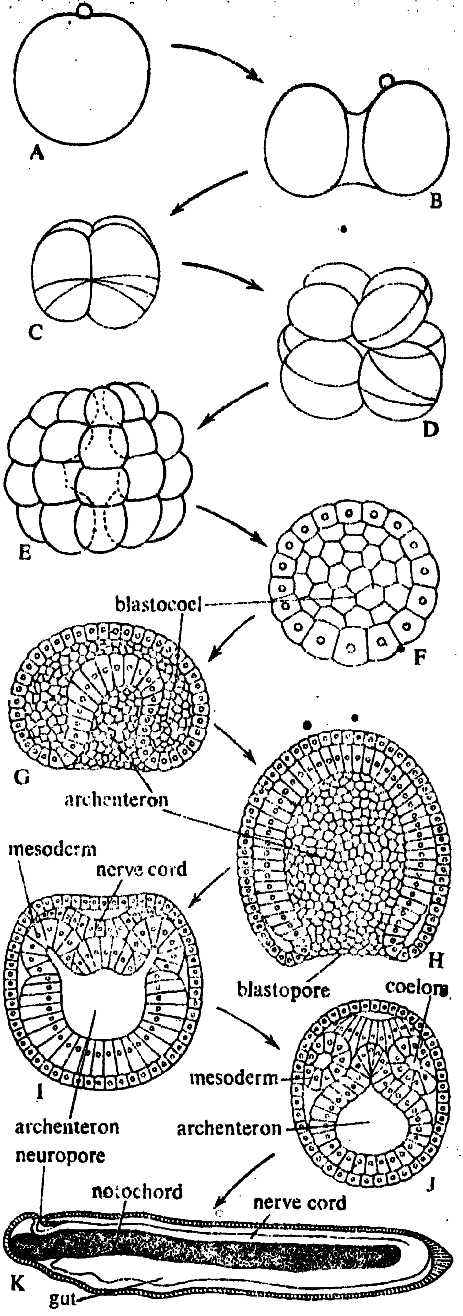


Fig. 2.10. Developmental sequences of *Branchiostoma*. A. Zygote prior to segmentation. B. Two-celled stage. C. Four-celled stage. D. Eight-celled stage. E. Thirty two-celled stage. F. Blastula. G. Early gastrula. H. Late gastrula. I. Three somite-stage. The mesoderm and nerve cord have been differentiated. J. Six somite-stage. Complete separation of mesoderm with the coelom is noticed. K. Longitudinal section of *Branchiostoma* immediately after hatching. Note that the F-K are all sectional views.

teron wall differentiates into the endoderm and the notochord is an endodermal derivative. The outpouchings of the archenteron wall transform into the mesoderm. These pouches proceed ventrally on the two sides of the gut and forms the splanchnopleure when applied to the gut wall and the somatopleure when attached to the body wall. The splanchnopleure on the sides of neural tube develops into the myotomes and fin-ray boxes.

The larva becomes active when it attains two gill-slits and moves about by its epidermal cilia. The mouth develops as a round aperture. The endostyle develops gradually. The larva with eight pair of gill-slits remains unchanged for a considerable period and many paired gill-slits appear on the pharyngeal wall as a result of subdivision of these gill-slits. The larva then sinks down to the bottom and becomes metamorphosed into an adult. In a few species of this genus, the larval stage continues for a longer period and the larva even shows the development of gonads. For this reason it was wrongly thought to be a new genus *Amphioxides*.

HISTORY

The first individual of this group was described by Pallas in 1774. He regarded the specimen as a slug and named it *Limax lanceolatus*. Yarrell (1836) studied the animal in details and gave the name *Amphioxus lanceolatus*. Costa (1834) suggested the name of the genus as *Branchiostoma*. Since then the biological name of the genus is established as *Branchiostoma* according to the laws of priority.

AFFINITIES AND SYSTEMATIC POSITION

Since its discovery, attempts have been made from time to time to determine the biological status of Branchiostoma. A number of groups of animals has been claimed to be related to Branchiostoma.

Interphylar Relationships

Many non-chordates have been regarded to be phylogenetically connected with Branchiostoma.

Relationship with Annelida

The concept of annelidan relationship with the Branchiostoma was mainly sponsored by Dohrn, Semper and Minot. The following features are common in the two groups: (1) The body is bilaterally symmetrical and segmented. (2) The nephridia are segmentally arranged and are provided with solenocytes. (3) Presence of well-formed coelom. (4) Similarity in the disposition of the blood vascular system. But this idea was confronted to serious difficulties, because the fundamental organisation of Branchiostoma differs widely from that of annelid. The points of homology become very difficult to establish on scientific grounds. In the annelids the segmentation is present throughout the entire length of the body, whereas in Branchiostoma the segmentation is restricted only to the myotomal region. The development of coelom is also different. It is schizocoelic in annelids and enterocoelic in Branchiostoma. Although the arrangement of the main longitudinal vessels is more or less similar in both, the direction of the flow of blood is diametrically opposite. Branchiostoma possesses all the diagnostic features of the chordates, like the notochord, dorsal tubular nerve cord and gill-slits. None of these three structures is observed in annelids, although 'Faserstrang' is homologised with the notochord.

Relationship with Mollusca

The ciliary mode of feeding and aerating mechanism in Branchiostoma resemble closely that of oysters. At the time of its discovery, Pallas (1774) regarded the specimen to be a slug and named it as *Limax*. The segmentation in Branchiostoma is a very important characteristic, but in molluscs the body is mostly unsegmented. The molluscan locomotory organ (foot) has no parallel in Branchiostoma. The anatomy of Branchiostoma is completely different from that of molluscs. The superficial semblances in the feeding and respiratory mechanisms may be interpreted as the result of physiological convergence for similar mode of living and it has no phylogenetic significance.

Relationship with Echinodermata

The phylogenetic relationship of the Branchiostoma with the echinoderms is quite convincing. The formation of coelom and mesoderm is strikingly similar in these two groups. The perforations in the calyx of some carpoid echinoderms are compared with the gill-slits of Branchiostoma. Biochemical studies also testify the common ancestry of the two groups of animals. The presence of creatine phosphate during energy transfer in ophiuroids and Branchiostoma, the phosphagens in echinoderms and Branchiostoma are the most important supporting biochemical evidences on this line. Echinoderms hold the key of chordate origin. The structural similarities of the Branchiostoma with the echinoderms are possibly due to inheritance from common ancestry.

Intraphylar Relationships

Inclusion of Branchiostoma under the phylum Chordata is universally accepted, because it possesses the notochord, dorsal tubular nerve cord and gill-slits. But its relative status within the phylum is still uncertain.

Relationship with Hemichordata

The hemichordates and Branchiostoma show many structural similarities. The similarities are: (1) The pharyngeal apparatus has similar structural construction. (2) Close similarity in feeding and respiratory mechanisms. (3) The development and arrangement of coelomic sacs are similar. These similarities are due to their emergence from a common echinoderm ancestor. But as regards its relative position, Branchiostoma occupies higher rank than the hemichordates. In hemichordates the muscles are unsegmented and most of the structures are rudimentary in nature. Besides, the existence of notochord in hemichordates has been questioned and the nervous system as a whole is built on more of nonchordate fashion. Considering all these points, the hemichordata must be regarded to be primitive than Branchiostoma from the evolutionary point of view.

Relationship with Urochordata

The urochordates and Branchiostoma are closely related with one another. The developmental story of urochordates provides the firm evidence to this view. The tadpole larva of urochordates resembles Branchiostoma very closely by the following features: (1) Presence of a continuous notochord. (2) A hollow nerve cord is located above the notochord. (3) The pharynx bears endostyle, dorsal lamina and peripharyngeal grooves. (4) The tail bears tail fin. The adult urochordates are extremely retrogreted forms. The feeding and respiratory mechanisms are similar. Most of the structures are evidently homologous and furnish a convincing evidence of closest phylogenetic relationship between the urochordates and Branchiostoma.

Relationship with Cyclostomata

The Ammocoetes larva of lamprey is strikingly similar to Branchiostoma. Both of them have the following features in common: (1) The mouth is surrounded by an oral hood. (2) A velum is present which guards the mouth. (3) An endostyle is present. (4) The body bears a continuous dorsal median fin. Branchiostoma resembles the adult cyclostomes, specially by having myotomes, persistent gill-slits and velum. But the absence of cranium, vertebral column and paired sense organs in Branchiostoma stands on the way. Because of the similarities, many authors regarded Branchiostoma as a permanent larval form of some species of cyclostomes exhibiting a case of 'paedogenesis'. But such a view requires more supporting evidences in its favour.

From the foregoing discussion on the anatomy and affinities of Branchiostoma, the systematic position appears to be unsettled. But its inclusion in the phylum Chordata is conclusive. Branchiostoma possesses an admixture of primitive, specialised and degenerated characters. In spite of the fact, it is regarded to be the vertebrates closest of kin, i.e., it represents a grade of structural organisation not too far from the vertebrate ancestor. Because of its degeneracy and semisedentary habit, Branchiostoma should not be regarded to be in the direct line of vertebrate evolution. An animal, showing degeneration in one hand and specialisation on the other, cannot possibly react to any evolutionary change. However, leaving aside all such controversies, it can be stated that Branchiostoma represents a fair theoretical picture of a chordate and fulfils the definition of Chordata in its strict sense.

SUBPHYLUM HEMICHORDATA (=ADELOCHORDATA OR STOMOCHORDATA)

IMPORTANT FEATURES

The subphylum Hemichordata includes marine forms. They are either tube-dwellers or burrowing forms. The body is divided into three regions *proboscis* (*protosome*), *collar* (*mesosome*) and *trunk* (*metasome*). The gill-slits are variable in number. The

Hemichordate (literally meaning half-chordate) forms a sort of structural bridge between the invertebrates and chordates.

OUTLINE CLASSIFICATION

The subphylum Hemichordata is classified into three classes, Enteropneusta, Pterobranchia and Planctosphaeroidea.

EXAMPLE OF THE HEMICHORDATA—

BALANOGLOSSUS

Balanoglossus is a widely distributed animal and inhabits all the seas of the world. The name Balanoglossus came from two Greek words, *balanos* meaning an acron and *glossa* meaning tongue which accords to the shape of the proboscis.

HABIT AND HABITAT

Balanoglossus is a burrowing animal. It may conceal under the stones or aquatic weeds. It is mostly an inhabitant of intertidal zone, although a few descend down to about 100m of the sea. Balanoglossus excavates its own burrows in sand or sandy mud. The burrow of *Balanoglossus clavigerus* is U-shaped with two openings 10 to 20 cm apart (Fig. 2.11). The anterior end of the burrow is funnel-like and the posterior end is round. The anterior vertical part of burrow may be branched. The animal moves inside the burrow. When the tide starts ebbing, the proboscis protrudes out of the burrow to explore the surface. The posterior end also projects out to expel the faecal matters. A constant secretion of mucus over the body causes adhering of sand grains over the body in the form of cast. Balanoglossus emits a peculiar odour resembling that of iodoform. This is regarded as a protective device. Balanoglossus is a sluggish animal and the proboscis is the most active part of the body. Burrowing process is exclusively done by the proboscis. The proboscis becomes elongated by the contraction of circular muscles and the shortening of the proboscis is caused by the contraction of its longitudinal muscles. The two sets of muscles are so coordinated that when one set contracts the other set relaxes and vice versa. Balanoglossus is less sensitive in response to external stimuli. It takes sand containing diatoms, protozoans and many other micro-organisms. The larval form (*Tornaria larva*) of Balanoglossus is a free-swimming planktonic form.

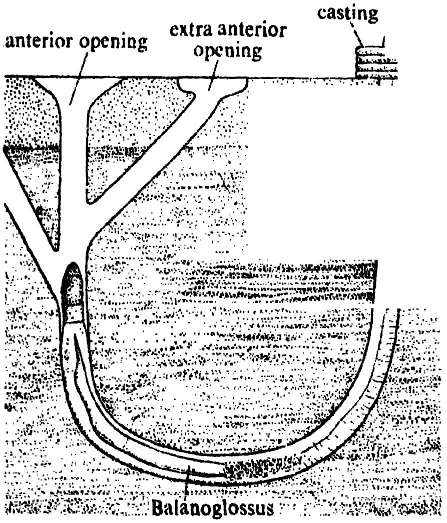


Fig. 2.11 *Balanoglossus* lives in U-shaped burrow.

EXTERNAL STRUCTURES

Balanoglossus is an elongated and worm-like animal. The length of the body ranges from 10–15 cm. The body is divisible into three major parts—the *proboscis* or *protosome*, *collar* or *mesosome* and *trunk* or *metasome* (Fig. 2.12A). The trunk is further subdivided into an anterior *branchiogenital region*, a median *hepatic* and the posterior *caudal* or *post hepatic region*. The proboscis is a short club-shaped structure forming the anteriormost division of the body. The proboscis narrows posteriorly to a *proboscis stalk*. It is hollow and communicates with the exterior by a single *proboscis pore* situated on the left side of the proboscis. The median part of the body consists of a flap of muscular tissue forming the collar. The proboscis is anterior to the collar. The proboscis stalk and a part of the posterior part of the proboscis are concealed by the collar. The collar cavity is paired and opens to the exterior by two apertures. The collar houses the mouth on the ventral side (Fig. 2.12B). The trunk is extremely long. The branchiogenital region is marked by a pair of thin flap-like longitudinal genital ridges which contain the gonads (Fig. 2.12C). Double rows of *gill-slits* are present on the dorsal surface of this region. The gill-slits increase in number as the animal grows older. The gill-slits are placed on a prominent elongated ridge. The hepatic region is externally marked by the sacculations of the intestine.

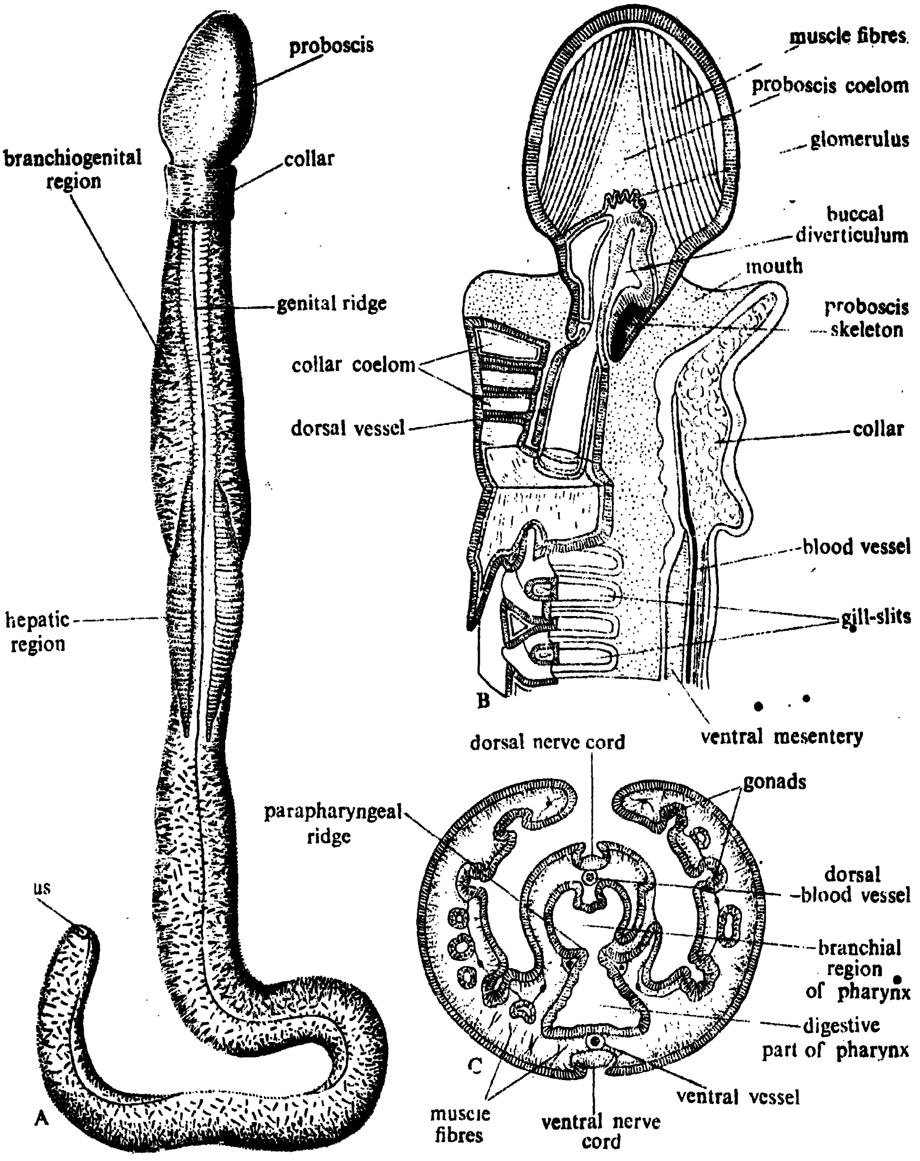

proboscis
branchiogenital region
collar
genital ridge
collar coelom
dorsal vessel
hepatic region
us
A
muscle fibres
proboscis coelom
glomerulus
buccal diverticulum
mouth
proboscis skeleton
collar
blood vessel
gill-slits
B
ventral mesentery
dorsal nerve cord
gonads
parapharyngeal ridge
dorsal blood vessel
branchial region of pharynx
digestive part of pharynx
C
ventral vessel
muscle fibres
ventral nerve cord

Fig. 2.12. A. External structures of a *Balanoglossus*. Note that the body is divided into three distinct parts. B. Diagrammatic saggital section of the anterior end of *Balanoglossus* showing the disposition of different internal structures in the proboscis, collar and branchiogenital portion of the trunk. C. Transverse section of the anterior end of the trunk.

The caudal region is more or less uniform in diameter and is marked externally by annulations. The trunk bears a midventral and a middorsal ridge which contain the longitudinal blood vessels and the longitudinal nerve.

BODY WALL

The body wall is composed of a ciliated *epidermis*. The ciliated cells are mostly tall and slender. The gland cells are also present in the epidermis. There are three types of gland cells: (1) *Reticulate gland cells*, where the cytoplasm contains mesh-like reticulum, (2) *Mulberry gland cells*, having coarse granules and (3) *Goblet cells*, which are filled up with fine granules or the cytoplasm is homogeneous (Fig. 2.13A). The cell body is divided into two parts—a ***distal flask-shaped expanded portion*** and a ***proximal slender***

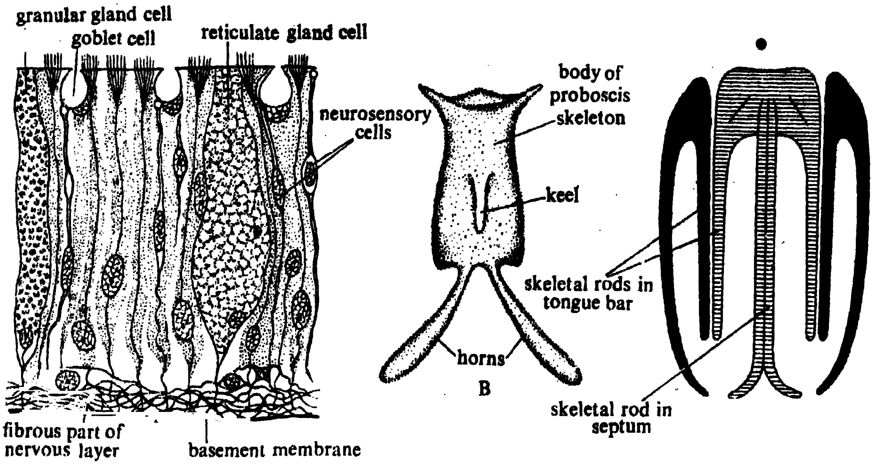


Fig. 2.13. A. Section of skin of *Balanoglossus*. B. The proboscis skeleton of *Balanoglossus*. C. Skeletal supports of the gill apparatus of *Balanoglossus* (after Hyman).

stalk. The stalk extends upto the base of the epidermis. The base of the epidermis is occupied by a thick *nervous layer*. A very thin connective tissue layer is present between the nervous layer and the epidermis. The nervous layer is separated internally by a well-developed *basement membrane*. The basement membrane is made up of two lamellae closely applied with one another.

Beneath the basement membrane, lies the *muscular sheath*. The circular muscle fibres are present in the proboscis and in the funnel-like anterior end of the collar (*collarette*). In the trunk region only longitudinal muscle fibres are recognised. The muscle fibres are of smooth variety. The inner side of the body wall is lined with parietal coelomic epithelium.

SUPPORTING STRUCTURES

NOTOCHORD OR BUCCAL DIVERTICULUM OR STOMOCHORD

The so-called 'notochord' in Balanoglossus is a questionable structure. The thick-walled anterodorsal hollow prolongation of the buccal cavity (*buccal diverticulum*) (see Fig. 2.12B) is considered by many workers, specially by Bateson (1885) as the notochord. It is called the *Stomochord* by Willey (1899). It extends into the proboscis cavity and is covered over by a sheath of basement membrane. It is composed of tall vacuolated endodermal cells. But topographically as well as developmentally this structure is quite unlike the true notochord of other chordates. The buccal diverticulum, according to most of the modern workers, is a preoral extension of the buccal cavity.

PROBOSCIS SKELETON

The basal part of the proboscis stalk and the roof of the buccal cavity are supported by a skeletal structure called the *proboscis* or *nuchal skeleton*. It is an 'Y'-shaped body and is composed of cartilagenous tissue. It has a *median plate* with two limbs (horns) diverging backwards (Fig. 2.13B). The proboscis skeleton has a lamellate body and is formed by the thickening of the basement membrane. The median plate is situated in the proboscis stalk and occupies a median position between the buccal diverticulum and the buccal epithelium. The median plate bears a midventral *keel*. The horns diverge posteriorly to support the roof of the buccal cavity.

BRANCHIAL SKELETAL RODS

The tongue bars and their septa are supported by skeletal rods. These skeletal rods, like those of proboscis skeleton, are formed by the thickening of the basement membrane. Each skeletal piece has got the appearance of a hair pin. One prong of the skeleton is present in the septum and the other lies in the tongue (Fig. 2.13C), i.e., each tongue bar and septum get two prongs from two skeletal pieces. The skeletal pieces of the adjacent septa are connected by transverse rods called the *synapticulae*.

LOCOMOTION

Balanoglossus is a sluggish animal and spends most of its time in burrows. The cilia present on the outerside of the body help in locomotion. The animal moves by alternate lengthening and shortening of the body produced by the action of muscle fibres. It moves first by the vigorous forward protrusion of the proboscis and collar and then draws the rest of the body towards the direction of movement by dragging. The relative position of the buccal diverticulum and the proboscis skeleton makes the proboscis and collar stiff. The stiffness of the proboscis and collar helps in burrowing through the sand. Balanoglossus utilises the cilia for normal movement and the muscles are employed only during emergency escape.

COELOM

Balanoglossus possesses a spacious coelom. The coelom is enterocoelous in origin and is lined by coelomic peritoneum. The original cavity of the coelom is greatly reduced by the presence of fibrous network and muscle fibres. In some regions the coelomic epithelium is found to be lacking due to its transformation into other tissues.

Coelomic sacs are present in the body of Balanoglossus. The *proboscis coelom* is an unpaired cavity. This cavity is greatly reduced by the connective and muscular tissues except a central space which accommodates the *proboscis complex* The buccal diverticulum, central sinus, heart vesicle and glomerulus constitute the proboscis complex. The proboscis coelom opens to the exterior through a proboscis pore by way of tubular *proboscis canal*. In all species under this genus have one proboscis pore and canal, but *Balanoglossus australiensis* has two such canals and pores. Such occurrence is an individual variation. The *collar coelom* is shifted as a pair of sacs between the buccal tube and the collar wall. The collar coelom and the proboscis coelom are not communicated with one another. Absence of septum between the proboscis and collar is an important feature in the anatomy of Balanoglossus. The dorsal and ventral mesenteries separating the collar coeloms are mostly incomplete. In the proboscis stalk the posterior end of the proboscis coelom and the anterior end of the collar coeloms secrete a stiff *chondroid tissue*. It resembles the vertebrate cartilage and surrounds the main plate of the proboscis skeleton as a network. The collar coeloms communicate to the exterior by the *collar tubes* and *collar pores*.

Like that of collar coeloms, the *trunk coelom* is divided into two lateral halves by the presence of dorsal and ventral mesenteries. The former one is incomplete at many places which permit mixing of coelomic fluid in the two trunk coeloms. The ventral mesentery is complete. The collar coeloms and the trunk coeloms are separated by *collar-trunk septum*. Each trunk coelom projects into the collar in the form of two evaginations, one is digitiform called the *perihaemal space* and the other is *peribuccal space*. The peribuccal spaces are less developed in this genus. The evaginations push the collar-trunk septum into the collar and thus make the collar coelom complicated.

The coelomic fluid contained in the different coelomic cavities is different in composition. As the proboscis coelom and the trunk coeloms have external communications, the coelomic fluid contains largely the sea water. But the coelomic fluid present in the trunk coeloms has amoeboid coelomocytes and the fluid is coagulated in histological fixatives.

DIGESTIVE AND RESPIRATORY SYSTEMS

The alimentary canal is a straight tube running between the *mouth* and *anus*. It is peculiar because musculature is absent. The mouth is a large opening situated on the ventral side of the collar. Formerly, the mouth was regarded to remain permanently opened. But Knight-Jones has shown that the mouth is capable of being closed or opened. There are two sets of muscle fibres, the radial fibres which open the mouth and the sphincter muscles which close it. The mouth leads into a short *buccal tube* contained in the collar. From the roof of the buccal tube, a buccal diverticulum is protruded into the proboscis coelom. The details of the buccal diverticulum is already discussed under the heading supporting structures. The buccal tube opens into the *pharynx*.

The pharynx is an elongated structure and plays the double role of food concentration and respiration. The physiological differences are marked by the morphological divisions of the pharynx. A *parapharyngeal ridge* on each side divides the cavity of the pharynx into two incomplete halves—a dorsal respiratory half pierced by gill-slits and a ventral half helps in food concentration (see Fig. 2.12C). The pharynx leads into a short *oesophagus* which is followed posteriorly with the *intestine.* The intestine is a straight tube and is distinguishable into an anterior *hepatic region,* marked by the sacculations of the dorsal wall of the intestine, and a narrow *post-hepatic region* that opens to the exterior through the *anus.*

The branchial region of the pharynx is perforated by a longitudinal series of gill-slits. The number of gill-slits varies and the number increases as the animal grows older. Each gill-slit is a U-shaped aperture (Fig. 2.14A). In Balanoglossus, the gill-slit, starts development as an oval slit. Subsequently the dorsal end of the aperture projects downwards as the tongue bar (Fig. 2.14B). The tongue bars are immovable and remain fixed. The tongue bar does not touch the ventral side of the gill-slit as a result each gill-slit assumes a U-shaped appearance. The portions of the pharyngeal wall separating the successive gill-slits are called the *septa.* The septa are solid, but the tongue bars are hollow which contain the coelomic cavity. The septa and the tongue bars are supported by skeletal rods.

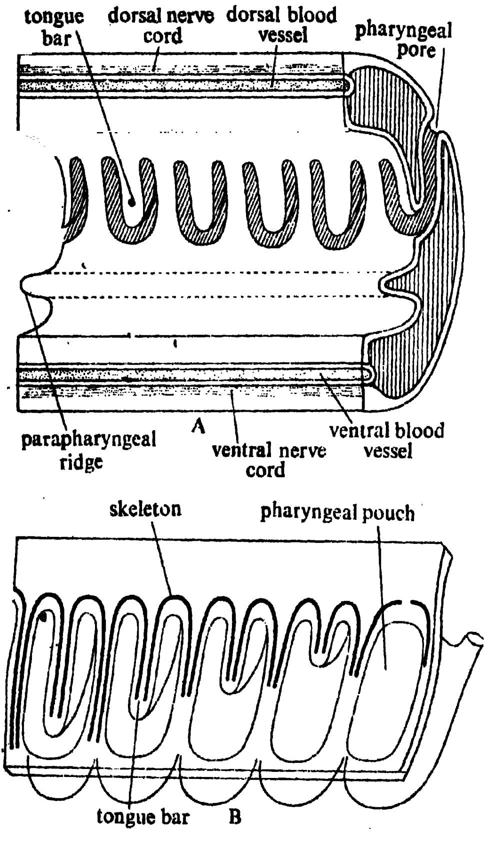


Fig. 2.14. A. Diagrammatic section of the body wall of the branchiogenital part of the trunk of *Balanoglossus* showing the relationship of branchial pouches with the pharynx. B. Developmental events of tongue bars in *Balanoglossus* (after Jollie).

The gill-slits have no direct openings to the exterior. Each gill-slit leads into a pouch-like cavity called the *branchial sac* which in turn opens to the exterior by the gill-pore. All the species under the genus *Balanoglossus* have separate gill-pore for each branchial sac, but in *Balanoglossus misakiensis,* the first four branchial sacs fuse with each other and open to the exterior through a common gill-pore (see Fig. 2.16A). The gill-pores are situated along a longitudinal groove called the *branchiogenital groove* which also contains the *gonopores.*

Feeding and digestion

Balanoglossus takes sand as it burrows through the sand. The mucus, secreted by the proboscis, entangles the sand or other food particles from the surrounding region. The mucus coated particles are pushed directly into the mouth by the action of cilia (Fig. 2.15). The cilia in the gill apparatus indirectly help in feeding process, because a ciliary current is always main-

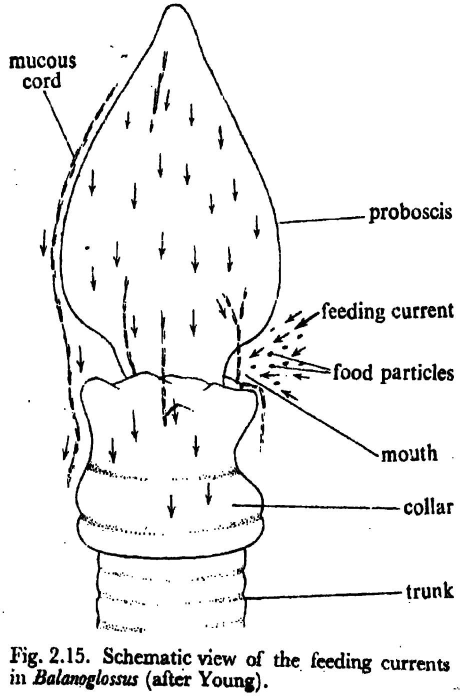


Fig. 2.15. Schematic view of the feeding currents in *Balanoglossus* (after Young).

tained through the mouth by the lashing of the cilia operating there.

The process of digestion is not known in Balanoglossus. But in a related genus, *Saccoglossus*, the process of digestion has been recorded. As described earlier, the entire alimentary canal is ciliated and the backward beating causes the movement of the food posteriorly. Peristalsis is observed in the first sector of the alimentary canal. The oesophagus is the most glandular part of the alimentary canal and is regarded to be the site of secretion of enzymes. The proboscis slime contains amylase. The hepatic region of intestine produces traces of protease, maltase and lipase.

Respiratory mechanism

Like cephalochordates, the cilia present in the gill apparatus and in the pharyngeal cavity help to maintain a powerful current of water. The water current enters into the mouth and goes out through the gill-pores. The incoming water current brings food as well as fresh oxygen dissolved in water. During the expulsion of the water through the gill-pores, the carbon dioxide goes out along with the exhalant water current.

CIRCULATORY SYSTEM

The circulatory system is well-developed in Balanoglossus (Fig. 2 16C). It comprises of blood, propulsatory heart vesicle, definite blood vessels and lacunar spaces. The blood is colourless and contains a few detached endothelial cells.

There are two main longitudinal blood vessels running along the length of the body. The *dorsal vessel* is situated just below the dorsal nerve cord and is contained in the dorsal mesentery. The blood flows anteriorly through the dorsal vessel. The ventral

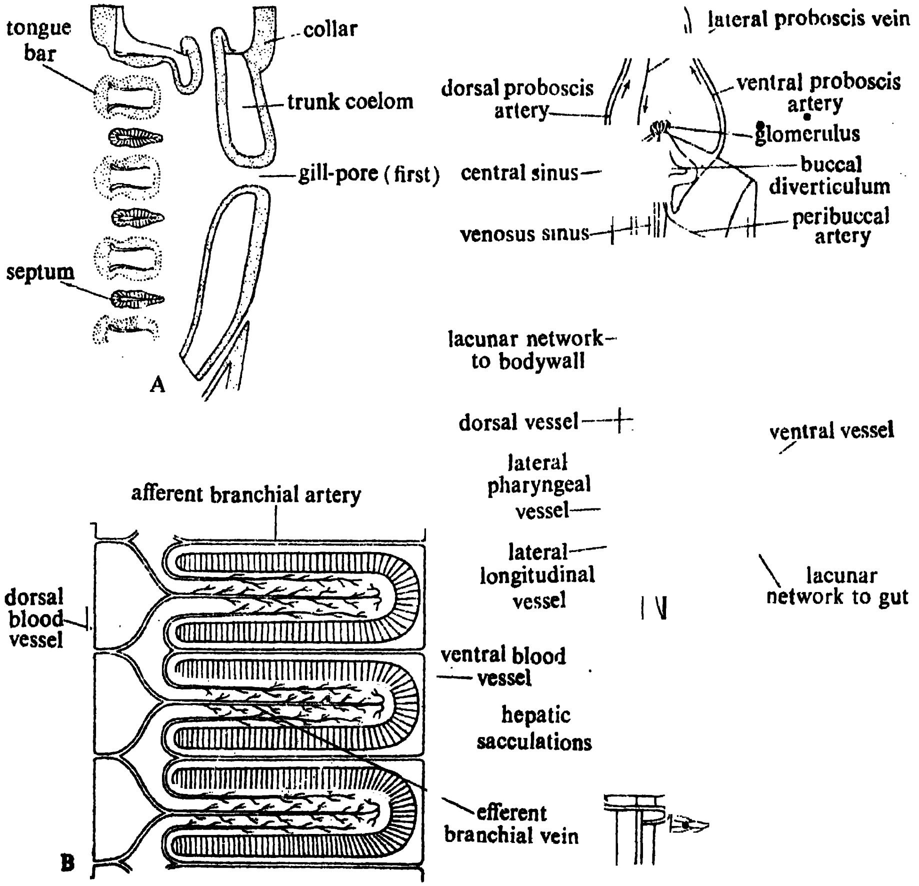

tongue bar
collar
trunk coelom
gill-pore (first)
septum
A
lateral proboscis vein
dorsal proboscis artery
ventral proboscis artery
glomerulus
central sinus
buccal diverticulum
venosus sinus
peribuccal artery
lacunar network-to bodywall
dorsal vessel
ventral vessel
lateral pharyngeal vessel
lateral longitudinal vessel
lacunar network to gut
ventral blood vessel
hepatic sacculations
efferent branchial vein
afferent branchial artery
dorsal blood vessel
B

Fig. 2.16. A. Longitudinal section of a side wall of branchiogenital portion of trunk in *Balanoglossus*. Note that the first four gill-slits open by a common gill-pore. B. Circulation in branchial apparatus of *Balanoglossus*. C. Circulatory system of *Balanoglossus*.

vessel is located in the ventral mesentery and in it the blood flows posteriorly. These two blood vessels are highly contractile and the walls are composed of an inner endothelium surrounded by muscle layer.

The dorsal vessel extends from the anus to the collar where it takes a median position between two perihaemal cavities. The dorsal vessel at this region expands to form *venosus sinus* which passes anteriorly into a *central sinus* or *heart*. The central sinus is situated above the buccal diverticulum. Immediately on the dorsal side of the central sinus there is a triangular sac called the *heart vesicle*. The blood passes directly into the glomerular cavities from the central sinus. From the glomerulus, the blood is collected by the four vessels. These vessels are regarded as the arteries because the blood leaving the glomerulus is regarded to be purified The arteries are: (1) a middorsal *proboscis artery*, (2) a midventral *proboscis artery* and (3) two *efferent glomerular arteries*. The middorsal and midventral proboscis arteries supply blood to the proboscis wall. The efferent glomerular arteries run backward on the two sides of the buccal diverticulum. These vessels then run ventrally to encircle the buccal tube as the *peribuccal arteries*. The peribuccal arteries unite together ventrally to form the *ventral longitudinal vessel*.

The ventral longitudinal vessel gives origin to a *ventral collar vessel* to supply the collar. The collar tissues contain two distinct lacunar networks which communicate posteriorly with a *ring vessel*. The ring vessel is located in the collar-trunk septum. It arises from the ventral longitudinal vessel and is connected with the dorsal longitudinal vessel. The ventral longitudinal vessel continues up to the anus and gives off lacunar networks all along the alimentary canal. The ventral longitudinal vessels give out a vessel in each gill septum which bifurcates to supply the two adjacent tongue-bars. Thus, each tongue-bar receives two *afferent branchial arteries* which break up into a plexus. From this plexus an *efferent branchial vein* is formed. It runs dorsally upto the middle of the tongue bar and joins with the efferent branchial vein of the adjacent tongue bar. The common branchial vein opens into the dorsal longitudinal vessel (Fig. 2.16B). The blood from the intestinal plexus in the trunk region is collected mostly by the dorsal longitudinal vessel.

EXCRETORY SYSTEM

A mass of coelomic evaginations in the proboscis complex is regarded as the excretory organ. Because of its similarities with the glomeruli of vertebrate kidney, the organ is regarded as the *glomerulus*. The glomerulus is situated on either sides of the heart vesicle and assumes the shape of the heart vesicle and the central sinus (see Fig. 2.12B). The cavities of the glomerulus are filled with blood which is confluent with the blood of the central sinus. The covering of the glomeruli is composed of excretory cells called the *nephrocytes*.

Besides the glomerulus, some cells in the proboscis peritoneum, connective and chondroid tissues of the collar and proboscis are regarded to be excretory in function. These excretory cells are named as the *paranephrocytes* or *arthrocytes*.

NERVOUS SYSTEM

The nervous system of Balanoglossus represents a very primitive condition. It consists of an intraepidermal nervous layer at the base of the epidermis. The nervous layer is composed of longitudinal nerve fibres with *bipolar* and *multipolar nerve cells* at the margin. The nervous layer becomes thickened to form two *nerve cords*, one is situated in the middorsal and the other in the midventral lines of the trunk. The ventral and the dorsal trunk cords are connected by a *circumenteric* or *peribranchial nerve ring* along the collar-trunk septum. The dorsal trunk cord in the collar leaves the epidermis and projects into the collar coelom as the *collar cord or neurocord*. The collar cord is situated above the buccal tube and contains a continuous lumen in other hemichordates. But such a lumen is not seen in Balanoglossus. The cellular nerve cord contains many giant nerve cells with axons projecting anteriorly and posteriorly. These are regarded to control the contraction of the body. In the base of the proboscis the nervous layer becomes thickened to form a *circular anterior nerve ring*. From the anterior nerve ring longitudinal nerve fibres are given out. There is no central nervous system in Balanoglossus. Isolates, from any part of the body, exhibit local reflex responses to touch or light source for a considerable period.

There is no special organ of sense. Extending all over the body, there are receptor cells which mostly respond to tactile stimulation.

REPRODUCTIVE SYSTEM

Balanoglossus reproduces normally by sexual process. Asexual reproduction occurs very rarely.

Sexual Reproduction

The sexes are separate, but the males and females cannot be distinguished externally. The gonads are sacculated bodies arranged as longitudinal rows outside the coelom of the branchiogenital region of the trunk (see Fig. 2.12C). Many secondary gonads are produced from the primary gonads. Each gonad proliferates and bulges into the coelomic cavity. Each gonad is covered by somatopleure and forms a slender tubular neck which opens externally by a *gonopore*. The gonopores are situated in the branchiogenital groove. The gametes are discharged to the exterior and the fertilization is external.

The eggs are small. The yolk content is very poor.

Asexual Reproduction

Asexual reproduction is an unusual phenomenon and occurs in *Balanoglossus capensis* which reproduces by separating off a small fraction of the body from the posterior end in summer. These fragments regenerate into sexual adults.

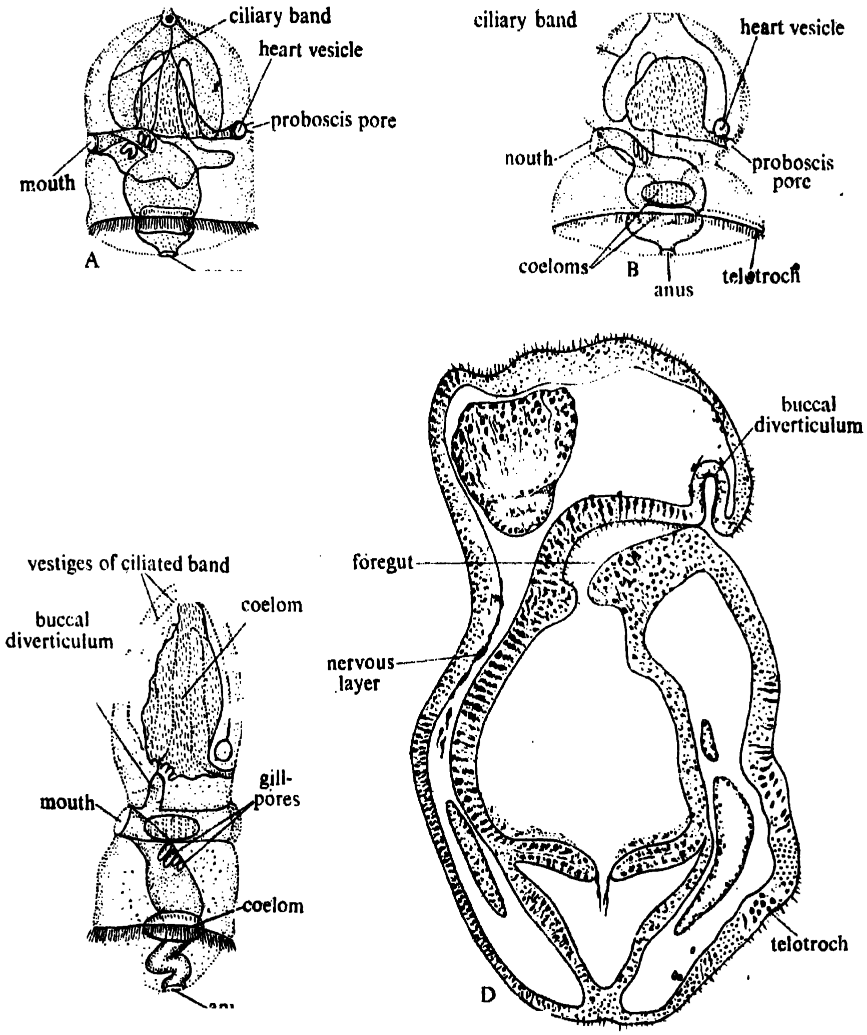

ciliary band
heart vesicle
proboscis pore
mouth
A
ciliary band
heart vesicle
nouth
proboscis pore
coeloms
B
anus
telotroch
vestiges of ciliated band
buccal diverticulum
coelom
mouth
gill-pores
coelom
buccal diverticulum
foregut
nervous layer
telotroch
D

Fig. 2.17. Larval development in *Balanoglossus*. A. A full-grown Tornaria larva. B-C. Stages of subsequent metamorphosis of Tornaria larva. D. Section through Tornaria larva showing the development of the buccal diverticulum (after Wilmoth).

REGENERATION

Balanoglossus exhibits great regenerative potency. Isolated pieces from the trunk have the inherent property to regenerate the lost parts.

DEVELOPMENT

The development is indirect, i.e., the development is followed by the metamorphosis of a well-developed larval form.

Prelarval development. The prelarval developmental stages resemble closely to that of Branchiostoma. The cleavage is holoblastic and occurs mostly along the radial planes. The resultant blastomeres are approximately equal, except the micromeres which are slightly smaller. A coeloblastula is produced which is transformed into a gastrula by invagination within 24 hours. The developing embryo elongates along the anteroposterior axis and develops cilia. The mouth and the anus are formed anew. The coelom develops by enterocoelic method. After about 24 to 36 hours, the embryo escapes as a larva. This larva was first observed by Johannes Muller (1850) who gave the name *tornaria* because of its habit of rotating in circles.

Larval development—Tornaria larva. The tornaria larva has an oval body with bilaterally symmetrical and looped *ciliated bands* (Fig. 2.17A). The size of the tornaria larva varies from 1-3 mm. The mouth is present on the ventral side near the equatorial plane of the body. The portion of the body anterior to the mouth is prolonged into a *preoral lobe*. Anterior end of the preoral lobe bears a distinct *apical plate* bearing nerve fibres, ganglionic nerve cells, a tuft of inmobile cilia and a pair of pigmented eye-spots. The preoral and postoral ciliated bands unite for a short distance at the apical plate. Another circular ciliated ring is present around the anus. The ciliary band is called the *circumanal ciliated band* or *telotroch*. The cilia in this band are long and powerful to act as the chief locomotory organ of tornaria. The anus is located medially on the posterior end of the body. The digestive tract is distinguishable into oesophagus, stomach and intestine.

The tornaria larva possesses only one pair of gill-slits. Five coelomic cavities are present which exhibit the trisegmental condition of the body. Finally the tornaria larva sinks to the bottom and metamorphoses into an audlt (Fig. 2.17B-C). The body becomes divided into three parts by two constrictions. It then undergoes morphological changes to become an adult.

CLASSIFICATION

CLASSIFICATION IN OUTLINE

Subphylum HEMICHORDATA OR ADELOCHORDATA OR STOMOCHORDATA

CLASS **Enteropneusta,** e.g., *Protoglossus, Saccoglossus, Balanoglossus, Spengelia.*

CLASS **Pterobranchia,** e.g., *Cephalodiscus, Rhabdopleura* and *Atubaria.*

CLASS **Planctosphaeroidea,** e.g., *Planctosphaera pelagica.*

CLASSIFICATION WITH CHARACTERS

The subphylum Hemichordata includes mostly the solitary forms but some are colonial. The body has well-formed enterocoelous coelom and is regionated into three parts. A preoral buccal diverticulum is present which is regarded as the notochord by many workers. The nervous system is intraepidermal. The circulatory system is well-developed. This subphylum includes three classes—Enteropneusta, Pterobranchia and Planctosphaeroidea.

CLASS **Enteropneusta**

This class includes the acron worms having vermiform body. They are solitary forms. There are numerous gill-slits and the intestine is a straight tube. The arms are absent. The examples are: *Protoglossus, Saccoglossus* (*Dolichoglossus*), *Balanoglossus, Ptychodera, Glossobalanus, Spengelia, Schizocardium* and many others.

CLASS **Pterobranchia**

Some members are colonial. The gill-slits may be absent, if present, are few in number. The alimentary canal is U-shaped. The arms are tentaculated. The body is enclosed in an encasement secreted by the animals. This class includes three genera *Cephalodiscus, Rhabdopleura* and *Atubaria.*

CLASS **Planctosphaeroidea**

This class is represented by transparent, round and specialised tornaria larva with extensively branched ciliary bands. The alimentary canal is L-shaped. Example: *Planctosphaera pelagica.* This form is regarded as the larval form of some unknown hemichordates.

HISTORY

The first member of the Hemichordata was recorded by Eschscholtz (1825). He named the animal *Ptychodera* and regarded it as a holothurian. Subsequently, Delle Chiaje (1829) added another member *Balanoglossus clavigerus* to the group. Since then, many hemichordates have been put on records. All these hemichordates were included under the group *Enteropneusti* (Gr. *enteron*=intestine and *pneumon*=lung) as proposed by Gegenbaur (1870). Since then this group was called the Enteropneusta. Bateson (1885) studied the embryology of some enteropneusts and proposed the name Hemichordata to replace Enteropneusta. The tornaria larva was regarded as an echinoderm larva by Johannes Muller (1850), Krohn (1854), Agassiz (1864) and many others. Metschnikoff (1870) regarded tornaria as the larval stage of Enteropneusta. The work of Kowalevsky needs special mentioning, because he gave the accurate description of Balanoglossus. The hemichordate possessing an exceptionally elongated proboscis was named *Saccoglossus* by Schimkewitsch (1892), but Spengel (1893), in his monograph, treated the same animal as subgenus *Dolichoglossus* under the genus Balanoglossus. Van der Horst (1939) regarded Saccoglossus and Dolichoglossus as the synonymes of the same genus.

Sars (1867) and Allman (1869) recorded the strange colonial *Rhabdopleura* as a member of Bryozoa. Lankester (1877) introduced the term Pterobranchia for Rhabdopleura, but still retained it as a subdivision under Bryozoa. Another similar animal *Cephalodiscus* was recognised by McIntosh (1882) which was also regarded as a bryozoan. Hamer (1887) and Fowler (1892) removed *Cephalodiscus* and *Rhabdopleura* respectively from the group Bryozoa and suggested their inclusion under Hemichordata. Another genus *Atubaria* was added to the group by Sato in 1936.

Willy (1899) divided the Hemichordata into two classes Enteropneusta and Pterobranchia. But Harmer (1905) added another class Phoronidea under Hemichordata. A peculiar pelagic larval form was discovered by Mortensen in 1910. Spengel (1932) named this larva as *Planctosphaera pelagica* and regarded it as the larva of some unknown hemichordates. So an additional class Planctosphaeroidea was created to accommodate it. Thus the group Hemichordata, as stands today, is divided into three classes—Enteropneusta, Pterobranchia and Planctosphaeroidea.

AFFINITIES AND SYSTEMATIC POSITION

Balanoglossus has a peculiar anatomical organisation. Its systematic position in the animal kingdom is still uncertain. Almost all the invertebrate phyla have been suggested to be nearest to the Hemichordata. Many authors have claimed Hemichordata as a separate phylum under the invertebrates. Some of the views existing on this particular aspect of Balanoglossus is described below.

Nonchordate affinities. Balanoglossus shows many structural similarities with invertebrates.

Relationship with Annelida. Many authors like Dohrn (1875), Semper (1876) and Minot (1897) have attempted to bring Balanoglossus and Annelids on the level of a distinct genetic relationship. The relationship was based on the following points of similarities: (1) Both of them have a vermiform and coelomate body. (2) The arrangement of the blood vessels is similar. (3) The collar of Balanoglossus is comparable to the clitellum of oligochaetes. (4) The Trochophore larva of annelids bears close structural semblances with the Tornaria larva specially in the apical sense organ and the ciliate rings. Despite such resemblances, these two groups are fundamentally different. The Trochophore larva bears a pair of nephridia which is absent in Tornaria larva.

Relationship with Phoronida. Masterman advocated the relationship of Balanoglossus with the Phoronida. The Actinotrocha larva of Phoronis and the Tornaria larva show the following points of similarities: (1) Both have similar disposition of the coelom. (2) The anus is surrounded by a ring of cilia. (3) The proboscis pore is comparable to the water pore of the Actinotrocha. Many authors have placed the phoronids under a separate order of the Hemichordata. Masterman gave the strongest support to this idea.

Relationship with Echinodermata. Adult echinoderms and adult Balanoglossus are structurally different, but the respective larval forms exhibit close similarity. Because of this fact, many zoologists have tried to establish such relationship on a solid foundation. Both the larvae have the following common features: (1) The origin and development of coelom are same. (2) The larval alimentary canal has similar subdivisions. (3) The position of mouth and anus is similar. (4) Both the larvae possess similar twisted ciliated bands. (5) The larvae are free-swimming. Such deep and fundamental similarities existing between the two larval forms must be due to a remote common ancestry. They are regarded to be 'living relics' of the time when there were no difference between the chordates and echinoderms. But the presence of apical plate with eye-spots in Tornaria larva raises some doubt.

Chordate affinities

Inclusion of Balanoglossus under the phylum Chordata is not universally accepted. Because, of the three fundamental characteristics of the chordate organisation, the nature of notochord is really questionable. The recent workers do not accept the notochordal nature of the buccal diverticulum. The nervous system in general is typically an invertebrate type excepting the presence of lumen in collar nerve cord. The only important chordate feature remains in the gill-slits. Because of the reasons, some authors include the hemichordates under the invertebrates and others place them under an appendix to the phylum Chordata. In our present discussion the Hemichordata is given the status of a subphylum under the phylum Chordata by placing more emphasis on the presence of gill-slits, a feature not found in any invertebrate. This will help us to avoid controversies to a large extent.

Relationship with Urochordata.

The nearest existing forms of the hemichordates are the urochordates because, they exhibit many close similarities with the hemichordates. The similarities in the pharynx and the branchial apparatus are most convincing. The development of the central part of the nervous system is quite similar in both. The above relationship becomes difficult to establish because the chordate nature of the hemichordates itself is questionable. The resemblances are due to the fact that the hemichordates are very remotely connected with the central stock from which the urochordates have descended.

Relationship with Cephalochordata. Similarities in the structure and function of the branchial apparatus, in the arrangement of coelomic sacs and in development demand close relationship of the hemichordates with the cephalochordates. Presence of unsegmented muscle fibres in hemichordates and dissimilarities in the developmental history stand as barriers to establish any close relationship. Hemichordata must be regarded to be lower in rank than Cephalochordata, because most of the characters in Hemichordata are primitive and rudimentary in nature.

In spite of the best efforts to give a decisive fate, systematic position of Balanoglossus is still a debatable issue. In the present state of knowledge it is safe to give it and its allies a separate status of a subphylum, Hemichordata, under the phylum Chordata by ignoring the doubtful homologies and puting more importance on the presence of gill-slits. It cannot be denied that the hemichordates furnish a very remarkable demonstration of the fact that the chordates are phylogenetically related to the echinoderms.

SUBPHYLUM UROCHORDATA (TUNICATA)

IMPORTANT FEATURES

The subphylum Urochordata constitutes a unique group of animals under the phylum Chordata. The members of this subphylum exhibit a high degree of diversity in form, habit and habitat. In Urochordates, the notochord is confined to the tail region in the larval stage. Because of this characteristic, the name of the group is the Urochordata. The adults are mostly degenerate and sessile forms. The body is enveloped by the tunic or test. The free end of the body bears two openings, the mouth and the atriopore. The proximal part of the alimentary canal is greatly enlarged to form a spacious pharynx. The coelom is not recognisable. The urochordates are hermaphrodite and the development is through free-swimming tadpole larva. The urochordates exhibit certain exceptions to the chordates, like retrogressive metamorphosis, alternation of generations and the formation of colonies. Most of the urochordates are sac-like creatures inhabiting the sea-bottom and are popularly called the sea-squirts.

OUTLINE CLASSIFICATION

The subphylum Urochordata is subdivided into three classes. The classes are:

(1) Ascidiacea, (2) Thaliacea and (3) Larvacea or Appendicularia.

EXAMPLE OF UROCHORDATA—ASCIDIA

HABIT AND HABITAT

Ascidia is exclusively marine and occurs at all the depths of the sea. It is sessile in adult stage, but the larva is a free-swimming form. The adult remains attached to the bottom of the sea or other substrata by the base. Ascidia is a microphagous animal, i.e., it feeds on micro-organisms. The food materials are obtained by ciliary action.

EXTERNAL STRUCTURES

Ascidia, in adult stage, is a solitary animal having a bag-like body (Fig. 2.18A). The body is covered by a tough and translucent *tunic* or *test*. Because of the presence of tunic, the urochordates are also known as tunicates. The tunic is composed of a carbohydrate, *tunicin* (chemically related to *cellulose*) and 20% of *glycoprotein*. The tunic is secreted by the epidermis and contains scattered cells. These specialised cells are mesodermal in origin and have migrated into the test. The cells are embedded in a matrix of tunicin and glycoprotein. The most important cell-types are the large bladder-like cells. Numerous blood sinuses permeate the tunic. The free end of the body bears two apertures, one at the top called the *oral funnel* or *siphon* containing the *mouth* and the other is laterally placed and is called the *atrial funnel* or *siphon*. The *atriopore* is situated in the middle of the atrial funnel. The oral funnel is usually eight-lobed, while the atrial funnel is six-lobed in Ascidia. The atrial funnel is located at one side of the body. In living condition, current of water enters into the body through the oral funnel and goes out by the atrial funnel. If the animal is disturbed, the body wall contracts instantaneously, as a result, the water contained inside the body is expelled out like jets, so the common name 'sea-squirt' has been attributed to the specimen. The attached end of the body is called the *stolon* or *base*.

BODY WALL

The body, as already stated, is covered over by tunic. Underneath the tunic, there lies the true body wall composed of living tissues called the *mantle*. The mantle is covered by a single-layered *epidermis*. The epidermis is composed of cuboidal or squamous cells. The mantle contains muscle-fibres which extend to various directions. The longitudinal muscle-fibres are numerous. Non-metameric organisation is a notable feature in Ascidia. This means the mesoderm remains unsegmented.

COELOM

Due to extensive development of the atrium, the coelom is greatly reduced except as a few doubtful derivatives, like pericardial cavity, gonadal cavities, etc. Reduction of coelom is regarded to be a degenerative acquisition.

LOCOMOTION

Ascidia, in adult, is a fixed form. So the locomotion in true sense is absent. The movement is restricted to the contraction of the body by muscle fibres and the closure of the funnels. But the tadpole larva swims actively in water. The mechanism of swimming in the tadpole is exactly similar to that already described in Branchiostoma.

DIGESTIVE AND RESPIRATORY SYSTEMS

The mouth is situated at the centre of the velum placed in the posterior end of the oral funnel. The velum is provided with velar tentacles. The opening and the closure of the mouth are regulated by muscle bands. The mouth opens into a greatly enlarged sac-like pharynx.

The pharynx in Ascidia, as in other invertebrate chordates, performs two functions, one is food collection and the other is respiration. The pharynx extends nearly upto the base of the body and remains attached with the mantle along the ventral side. Except this region the whole of the pharynx is enclosed by a special cavity called the *atrium* (Fig. 2.18B). The atrium opens to the exterior through an atriopore. The pharyngeal wall and the body wall are connected by *trabeculae*. The wall of the pharynx is pierced by numerous vertically disposed apertures called the *stigmata*. The stigmata develop by the subdivision of a few (presumably three) gill-slits. Each gill-slit is divided by the developing tongue-bars which become connected by transverse connecting bars, the synapticulae. By this way numerous stigmata are produced out of a few gill-slits. The stigmata bear ser[illegible] of papillae containing muscles and cilia.

An endostyle is present inside the ventral

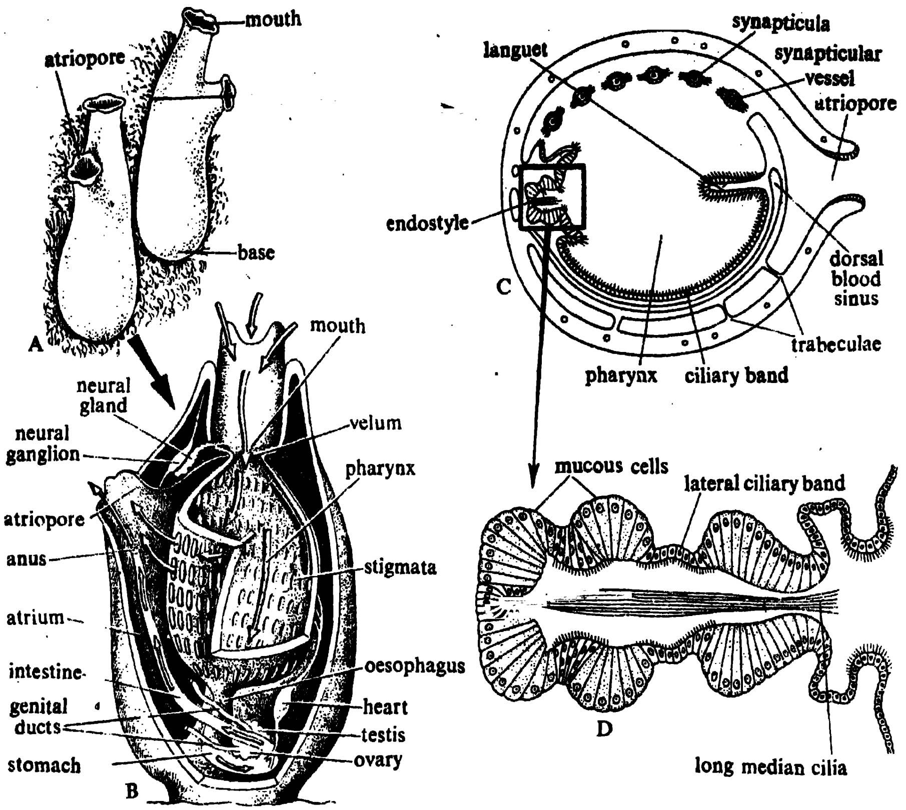

mouth
atriopore
base
A
mouth
neural gland
neural ganglion
atriopore
anus
atrium
intestine
genital ducts
stomach
B
velum
pharynx
stigmata
oesophagus
heart
testis
ovary
synapticula
languet
synapticular vessel
atriopore
endostyle
C
dorsal blood sinus
trabeculae
pharynx
ciliary band
mucous cells
lateral ciliary band
D
long median cilia

Fig. 2.18. Anatomical organisation of adult *Ascidia*.
A. Two intact adult animals. Note that the animals are sessile and are attached to foreign substratum. B. Saggital sectional view of the body. A part of the pharyngeal wall is removed to show the direction of water current. The arrows indicate the circulation of water current. C. Diagrammatic transverse section through pharyugeal region. D. An enlarged sectional view of the endostyle.

side of the pharynx. The endostyle has two rows of mucous cells on each side which are separated by row of ciliated cells. A group of median cells with very long cilia is present at the middle of the endostyle (Fig. 2.18D). The relationship of endostyle with the thyroid gland of vertebrates is advocated by many workers. The thyroid gland incorporates iodine. Experimental studies with the isotopes of iodine show that certain cells of the glandular tracts of endostyle incorporate the iodine. The opposite side of the endostyle is occupied by the *dorsal lamina* which is produced into numerous hanging curved bodies called the *languets*. The endostyle and the dorsal lamina are connected by the *peripharyngeal ciliary bands*.

The pharynx is connected with an expanded '*stomach*' by a short and narrow *oesophagus* (Fig. 2.18B). The stomach has a folded inner wall containing digestive glands. These glands secrete digestive enzymes, like protease, lipase, amylase and invertase. A pyloric gland composed of numerous small sacs or ampullae remains in contact with the intestine. Ductules arising from these ampullae unite to form a duct. This duct opens into the posterior end of the stomach. From the stomach a simple intestine ascends up and opens into the atrial funnel by the anus. The wall of the alimentary canal is nonciliated. The intestine is the absorptive portion of the alimentary canal. The wall of the intestine is thickened internally into a pad called the *typhlosole* which increases the absorptive surface of the intestine.

Food collection. The beating cilia in the stigmata set up a water current which enters into the pharynx and goes out through the atriopore via the stigmata. The food particles suspended in the water current are entangled by the mucus secreted by the glandular tracts of the endostyle.

The mucus entangled food particles move upwards and are then pushed back into the oesophagus by the ciliary action of the dorsal lamina. From the oesophagus, the food particles pass on into the stomach where they are subjected to the action of the digestive ferments. The digested food is absorbed in the intestine and the undigested products are expelled out through the anus and atriopore.

Respiration. The extensive ciliation in the pharyngeal cavity and the cilia bounding the stigmata set up a constant flow of water current passing inwards through the mouth. During the inflow of water current, the water, containing fresh oxygen in dissolved state, passes into the atrium via the stigmata. This process is supplemented by the periodic muscular contractions of the body wall. From the atrium the water goes out to the exterior through the atriopore. The walls of the stigmata are highly vascular where exchange of gases takes place. After oxidation, the resultant carbon dioxide passes out along with the water from the atrium.

CIRCULATORY SYSTEM

The circulatory system consists of blood, a heart, blood vessels and sinuses. The blood contains a colourless plasma and a few corpuscles. Some of the corpuscles are phagocytic and the others contain pigments. Red blood corpuscles are not encountered. Ascidia lacks the power of regulation of osmotic pressure, as a consequence the blood is isotonic with the sea water.

The heart is a fusiform sac-like structure which is surrounded by the pericardium. The heart is situated below the pharynx. The heart communicates with a system of blood spaces called the haemocoel. Some of the larger spaces have an endothelial lining and thus form the blood vessels. Below the endostyle the heart gives a *ventral* or *hypobranchial vessel* to supply the various parts of the pharynx. From the opposite end of the heart another vessel called the *visceral vessel* emerges out to supply blood to the viscera. The direction of the flow of blood through the heart is periodically changed due to the reversal of peristalsis of the heart muscles. Such a phenomenon is very rare and is not observed in the circulatory system of any animal.

EXCRETORY SYSTEM

There is no definite excretory organ in Ascidia. The *nephrocytes* present in the blood are found to accumulate excretory products in the cytoplasm. It is recorded that about 95% of the nitrogenous wastes are excreted in the form of ammonia. Julin suggested that the neural gland functions as the excretory organ. A peculiar hollow neural gland is found embedded in the ventral side of the nerve ganglion. The gland opens into the pharynx near the velum through a *ciliated funnel* (Fig. 2.19B). This gland originates mainly from the larval ectoderm and partly from the pharynx. This double origin is quite significant. The gland is regarded to be a homologous structure with the hypophysis of the vertebrates.

NERVOUS SYSTEM

The whole of the nervous system is reduced to a single elongated solid nerve

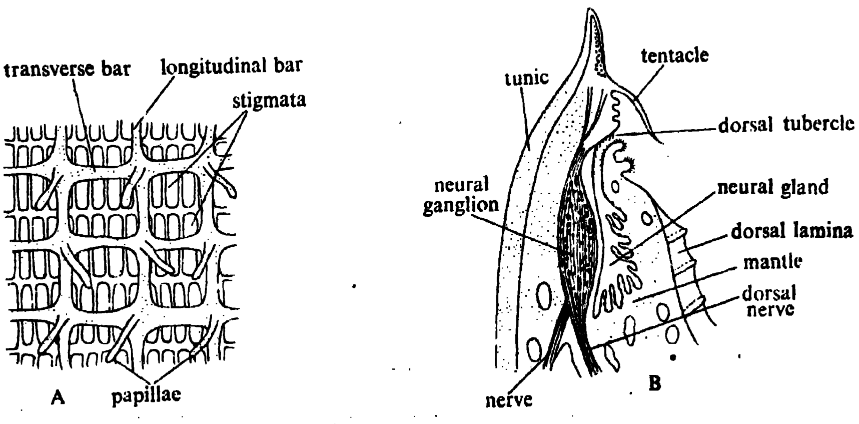


Fig. 2.19.A. A greatly enlarged view of a portion of the pharyngeal wall of *Ascidia*. B. A saggital sectional view of the anterodorsal part of the body wall to show the relationship between the neural ganglion and neural gland in *Ascidia*.

ganglion called the *cerebral ganglion* or *brain.* It is situated dorsal to the neural gland and between the atrial and oral funnels (see Fig. 2.18B). This ganglion gives nerves, specially to the atrial and oral funnels and velum and thus help to regulate the flow of water current.

SENSE ORGANS

The special sense organs in the strict sense, are absent. The pigment spots or *ocelli* that are present in the adults around the funnels are regarded to be the photoreceptors in a lowly developed condition. But in a fully-grown tadpole larva, the photoreceptive organ is highly developed.

REPRODUCTIVE SYSTEM

Ascidia is a hermaphroditic animal. The gonads are sac-like structures situated in close association with the intestine. The gonads are mesodermal in origin. The ovary and testis possess elongated gonoducts (see Fig. 2.18B). The gonoducts open into the atrium. The sex cells are discharged into the atrium and from there these are expelled to the exterior. Fertilization is external. The sperms and eggs mature at different times, thus self-fertilization is prevented. But in *Ascidia mentula*, self-fertilization takes place.

Besides sexual reproduction, multiplication by budding is not of rare occurrence. Ascidia is noted for its great potency of regeneration.

DEVELOPMENT AND LIFE-HISTORY

The marvel of life is nowhere more wonderfully displayed than the developmental history of an individual from the

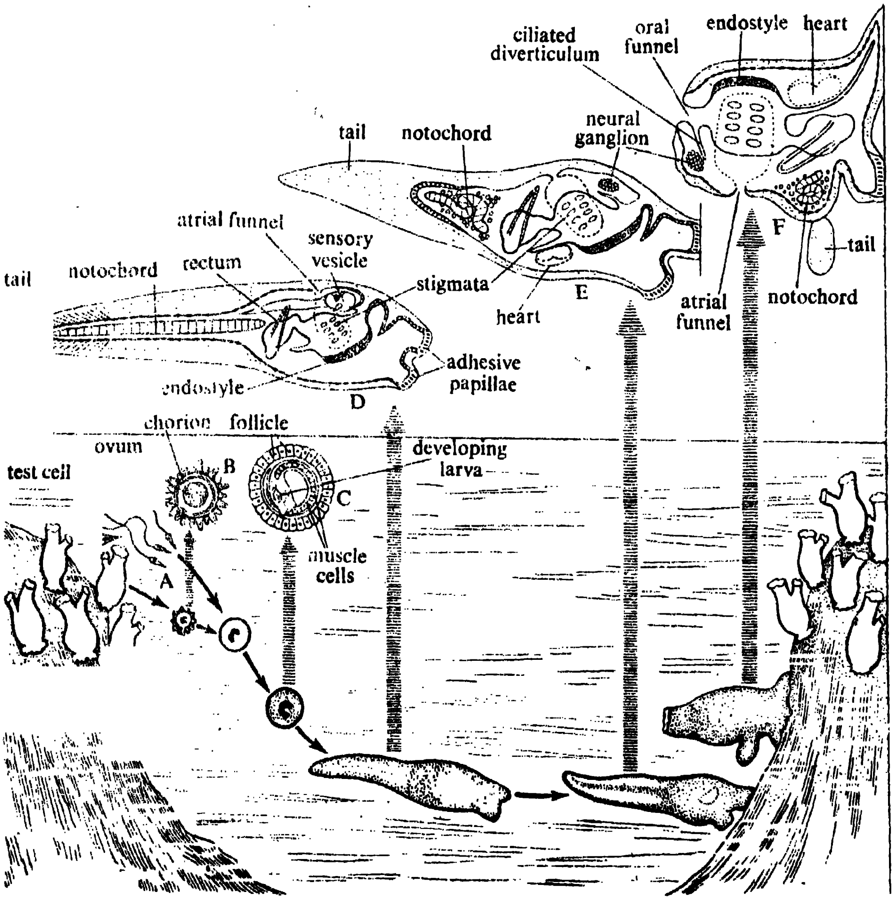

ciliated diverticulum
oral funnel
endostyle
heart
neural ganglion
tail
notochord
atrial funnel
sensory vesicle
tail
notochord
rectum
stigmata
heart
E
F
tail
atrial funnel
notochord
adhesive papillae
endostyle
D
chorion
follicle
ovum
test cell
B
developing larva
C
muscle cells
A

Fig. 2.20. Developmental sequences of *Ascidia*. A. Spermatozoa. B. Fertilized egg. C. Developing larva prior to hatching. D-F. Showing the metamorphosis of the free-swimming tadpole into the fixed stage. D. A full-grown free-swimming tadpole larva. E. The tadpole immediately after fixation. Note the reduction of the length of the tail. F. Advanced fixed tadpole. D-F. Sectional views.

zygote, the resultant product of fusion of the egg and the sperm. The ontogenic developmental process is mostly direct. But in a few cases the development is indirect, i.e., the development is accompanied by metamorphosis. The phenomenon of metamorphosis includes a series of changes which a larva (an immature individual of a species differing the adult both in morphology and physiology) has to undergo before attaining its adulthood. Metamorphosis, in most animals, is a progressive process. But there are some examples, where the developmental events are largely retrogresssive. Ascidia furnishes one of the best examples of retrogressive metamorphosis in which a highly developed tadpole larva, in course of ontogenic processes, transforms into a sessile and degenerated adult (Fig. 2.20). The retrogressive metamorphosis is a peculiar and uncommon process in the chordates, although such phenomenon is observed in some non-chordate animals.

Prelarval stages. The eggs are small and almost yolkless. Each egg is covered by some membranes which help the egg to float in water. The segmentation is holoblastic and nearly equal at the initiation. A blastula with a few cells is produced. Gastrulation is followed by invagination. The gastrula elongates and after about three days, a free-swimming tadpole larva emerges. The tadpole larva has all the characteristics of chordate organisation.

Larval stages. The larval form present in the life-history of Ascidia is called the tadpole larva. It is very active at the beginning which in course of metamorphosis transforms into a sessile adult (Fig. 2.20 D F).

STRUCTURE OF EARLY TADPOLE LARVA

A fully grown tadpole larva is highly motile and does not take food from outside, i.e., it is a nonfeeding form. It has an elongated body. The body is more or less oval in outline. It is distinctly divisible into two regions, the *head* and the *tail* (Fig. 2.20D). The whole of the body is covered over by tunic. The head is elliptical and has three *adhesive papillae* or *chin warts.* Of the chin warts, one is middorsally placed and the rest two are located ventrolaterally. The tail is laterally compressed and pointed terminally. It is provided with a *caudal fin.* The dorsal and ventral fins are continuous along the tail and are marked with *striae.* The striae are regarded to be precursors of the finrays in fishes.

The central nervous system is situated dorsal to the notochord. It enlarges anteriorly into a *sensory vesicle* which opens into the pharynx near the mouth by *neuropore.* A single median *eye* containing the retina, pigmented layer, cornea and lens is present in the inner wall of the hollow sensory vesicle. An *otocyst,* the organ of balance, is also situated in its ventral side. The slender nerve cord is not much differentiated but is hollow throughout. The notochord is restricted only in its tail region. It extends anteriorly upto the pharyngeal region and is ensheathed by gelatinous materials. Segmental muscle bands are present in the tail region which are arranged on both the sides of the nerve cord. The mouth is present and the alimentary canal is rudimentary. The pharynx is sac-like and is well-developed. It bears a fully-developed *endostyle* and two pairs of gill-slits. Nonfunctional heart with *epicardia* lies beneath the endostyle. The paired atrial sacs are present. Just after hatching the tadpole larva becomes positively phototactic and negatively geotactic.

Metamorphosis and emergence of adult

The free-swimming tadpole larva after a short period of free existence becomes sluggish. It soon fixes itself to sea weeds or stones by adhesive papillae and immediately falls a victim of fast degeneration. At this stage the larva becomes negatively phototactic and positively geotatic.

RETROGRESSIVE CHANGES

Just after fixation the length of the tail is greatly diminished. The nerve cord becomes restricted in the trunk region and is ultimately reduced to a solid nerve ganglion. The notochord becomes coiled, disorganised and finally disappears. The trunk becomes broadened. The number of the striae is diminished and become restricted to certain regions. The muscle bands also become degenerated. Gradually the tail is further shortened without having any striae. The mouth is shifted to 90° from the point of attachment (Fig. 2.20F). Shifting of the mouth is caused by the rapid growth of the region between the adhesive papillae and mouth and also due to inhibition of growth of the original dorsal side. As the development goes on, the tail becomes still more shortened and is partially withdrawn into the test. The rotation of the mouth is clearly marked.

PROGRESSIVE CHANGES

During metamorphosis from the tadpole larva to the adult, all the changes are not necessarily degenerative but some structures become more elaborated and specialised. The progressive changes are: (1) The branchial chamber becomes enlarged and the number of stigmata become enhanced. (2) The postpharyngeal portion of the gut gets regionated into different parts. (3) The atrium becomes more extensive. (4) The development of velum is observed. (5) The gonads and gonoducts appear from the mesoderm.

The foregoing description shows a wonderful scheme of retrogression of a complex and well-organised larval form to a simpler degenerated adult. This drastic change over is really a strange phenomenon because no external agency is recorded to act upon it. In the whole of animal kingdom, a parasitic crustacean, *Sacculina*, can be brought to the same status as far as the retrogression is concerned, if the external agency of parasitism is assumed to be absent from its life.

The essence of retrogressive metamorphosis in Ascidia is (*i*) the differential growth and disappearance of histologically differentiated larval tissues and (*ii*) the formation of the adult structures from the residual larval tissues. In ascidian metamorphosis, two sets of cnanges occur. First, the disappearance of notochord, nerve cord and muscle bands and secondly, the elaboration of some adult structures like the formation of stigmata, specialisation of pharynx, overdevelopment of atrium, etc. The most pertinent question in the metamorphosis remains why and how retrogression takes place in Ascidia by the destruction of the larval tissue. There are many views on this particular issue. Hardman regards phagocytosis as the primary cause of larval tissue destruction, while Berrill advocates that the relative tissue starvation is responsible for larval tissue destruction. Liberation of metabolites by the larval tissue accelerates metamorphosis. The larval tissue extracts and nontoxic solution of copper, iron, aluminium and iodine, have also been recorded to accelerate metamorphosis.

ZOOLOGICAL IMPORTANCE OF TADPOLE LARVA

The presence of tadpole larva in the life-history of Ascidia is very significant. From the taxonomical stand point, the tadpole larva helps us to include the ascidians under the phylum Chordata, otherwise their inclusion under the phylum would have been questionable. The existence of tadpole in their life-cycle appears to be either a case of recapitulation of the past racial history or it must be the birth right of a chordate. However, we can best regard the tadpole larva as a relic of the ancestral free-swimming chordate. Two contradictory views exist on the particular issue. The first view holds that the existence of tadpole larva is an interpolation in the life-history of Ascidia which by the suppression of metamorphosis and further evolution might have given origin to the ancestral chordate. The other view (exclusively of N. J. Berrill) holds that the existence of tadpole larva is not a case of interpolation. It has evolved within the group to meet certain ascidian needs. The tadpole larva holds the key, from which the vertebrates have emerged out in space and time.

EXAMPLE OF UROCHORDATA—HERDMANIA

Herdmania (=*Rhabdocynthia*) is a very common tunicate of the Indian seas. The morphology, habit and habitat of Herdmania are closely similar to that of Ascidia. It is very easily available and as such is extensively used as the material for dissection in many universities of India.

HABIT AND HABITAT

Herdmania is a solitary ascidian. It is exclusively marine. The genus is recorded to go to the depth of 9 m–21.6 m of the sea. The adult is a sessile form which remains attached to the substratum by its *base* or '*foot*'. It is a microphagous animal which feeds on microscopic animals and plants.

The tunic of Herdmania provides shelter for many organisms. Of a very common occurrence is the growth of a green alga on the tunic which sometimes hides the whole animal. The other organisms inhabiting the tunic are the hydroids, anemones, minute lamellibranchs, gastropods and many other animals.

EXTERNAL STRUCTURES

Herdmania has an oblong bag-like body. The species inhabiting the sandy bed is provided with a narrow '*foot*', but when the animals are attached to rocks or any molluscan shell, the 'foot' is found to be lacking. The attachment is done by a flat base. The animals with the 'foot' have their bodies divided into two parts, the *body proper* and the 'foot'. The size and shape of the animals vary greatly. The average size of the adult is recorded to be 9.5 cm in length. The foot, when present, measures about 3–4 cm in length. The free end of the body bears the *oral* and *atrial funnels* containing the oral aperture and atriopore respectively. Both these funnels are produced into four distinct lobes (Fig. 2.21A). The oral funnel is smaller than the atrial funnel. The whole of the body is enclosed by the *test* or *tunic*. The tunic is soft and leathery. The test is transparent in young stage which becomes opaque in the adult. In the young stage, a network of blood-capillaries is clearly visible through the transparent test. One of the important characteristic features of Herdmania is the presence of reddish patches on the body, produced by the ampullae at the terminal ends of the blood vessels

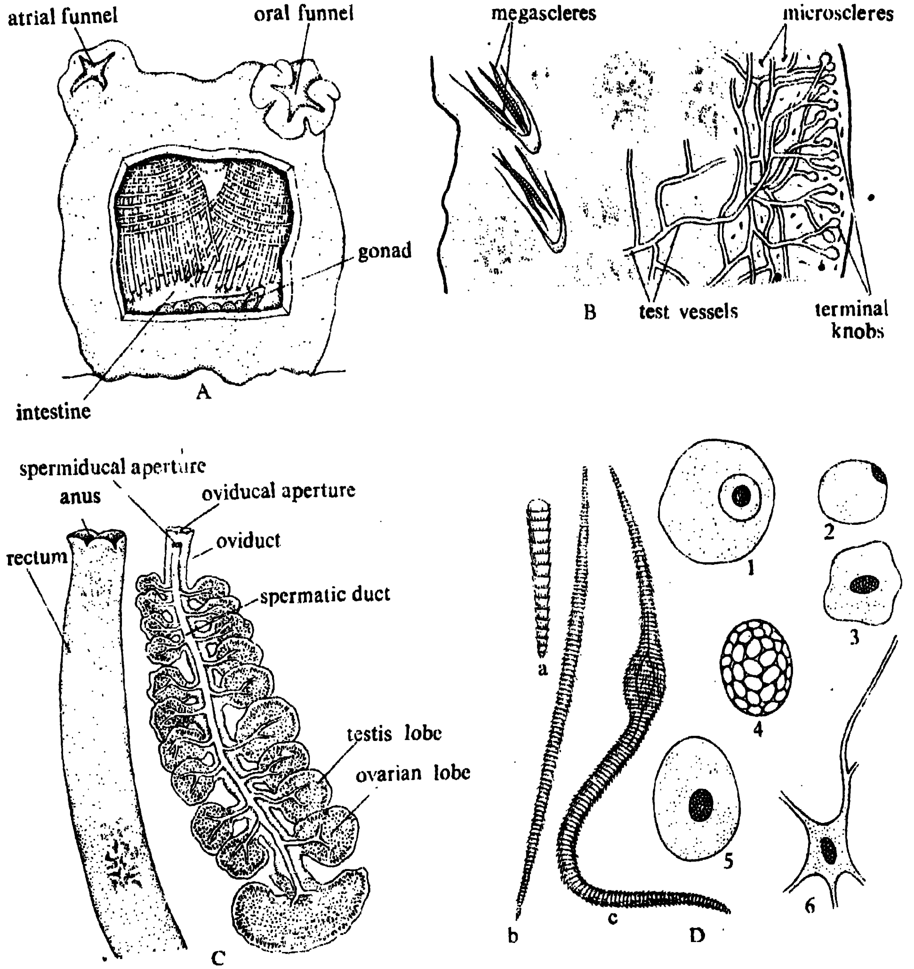

atrial funnel
oral funnel
gonad
intestine
A
megascleres
microscleres
B
test vessels
terminal knobs
spermiducal aperture
anus
oviducal aperture
oviduct
rectum
spermatic duct
testis lobe
ovarian lobe
C
a
b
c
D
1
2
3
4
5
6

Fig. 2.21. Anatomy of *Herdmania* (after Das).

A. An adult animal. A portion of the body wall is removed to show the internal structures. B. Section of the test. C. Sectional views of the gonads and gonoducts. Note the relationship with the rectum. D. Spicules and cell-types are a=microscleres. b=Spindle-shaped spicule. c=pipette-shaped spicule. 1=large eosinophilous cell. 2=small eosinophilous cell. 3=amoeboid cell. 4=vacuolated cell. 5=granular cell. 6=nerve cell.

in the test. The test acts as the accessory respiratory structure in Herdmania.

The mouth is situated at the base of the oral funnel and the atriopore is contained in the atrial funnel. The mouth indicates the anterior end of the body and its opposite end is the posterior. The dorsal side is marked by the atrial funnel, the opposite end of which is designated as the ventral side of the body. The bases of both the oral and atrial funnels are provided with a tentacular ring. The tentacles that surround the mouth are called the *oral* or *branchial tentacles* and that of the atriopore are called the *atrial tentacles*. The oral tentacles are comparatively longer than the small and vestigial atrial tentacles. The oral tentacles form a sort of sieving apparatus which prevents the entry of larger particles into the pharyngeal cavity. The internal cavity of both the funnels are lined by a thin layer of test which is folded. On these folds, red pigmented patches are present which are separated by white streaks. There are eight red patches arranged alternatively with eight white streaks. Both the patches and streaks extend from the tip of the funnels down to the basal end. In living condition, a strong water current is found entering the oral funnel and goes out through the atrial funnel.

BODY WALL

The test is the protective covering of the body. It is 4–8 mm thick and is composed of tunicin. In the ground substance of the test many structural elements are embedded. These are the meshwork of blood vessels, spicules, interlacing fibres and a few cell-types (Fig. 2.21B). Several cell-types are encountered in Herdmania (Fig. 2.21D). These are: (1) AMOEBOID CELLS—these cells are abundant in the test. (2) EOSINOPHILOUS CELLS—these are spherical cells and the cytoplasm contains homogeneous fine granules. The granules take bright red stain with eosin. The eosinophilous cells are of two varieties: (*a*) larger variety with a big vesicular nucleus and (*b*) smaller type with an eccentric nucleus. (3) GRANULAR CELLS—these cells are oblong in shape and the nucleus is large. These cell-types are surrounded by nerve fibres and are regarded as the receptor cells. (4) SPHERICAL VACUOLATED CELLS—containing numerous small vacuoles and the nucleus is not visible. (5) NERVE CELLS—these are small cells with conspicuous nucleus and two to six dendrites.

Besides, there are interlocking fibres running in the test. These fibres resemble with the muscle fibres of the mantle. The test is traversed by the blood vessels with their terminal ends dilated to form the *terminal knobs* or *vascular ampullae*. These ampullae impart red coloured patches on the outerside of the body. Another peculiar structure present in the test remains the spicules. The spicules are of two varieties: (1) MICROSCLERES and (2) MEGASCLERES. The microscleres are minute bodies having a spherical *head* and a long *body*. The body is beset with 5 to 25 equidistant rings of small spines. But the head is smooth in most cases. The average size is about 50 micra. The megascleres are larger than the microscleres and are grouped under two categories depending on the shape. The first category of spicules have spindle-shaped bodies, so these are called the *spindle-shaped spicules* and the second category of spicules are called the *pipette-shaped spicules*. The spindle-shaped spicules, like microscleres, are provided with 20–60 equally spaced rings of spines. The size is variable, but the average size being 1.5 mm. These spicules usually occur in bundles. The pipette-shaped spicules, as the name suggests, have a large round median swelling. These spicules are also provided with numerous rings of spines. The length of the spicules extend up to 3.5 mm.

Beneath the test lies the mantle. The mantle is the true cellular wall which surrounds the body. It is not uniformly developed at all regions of the body. The mantle is highly developed in the anterodorsal side of the body. The mantle is composed of (*i*) an outer epidermis, (*ii*) a median layer of muscles and fibres and (*iii*) an inner ectodermal layer lining the atrium. The epidermis is formed of hexagonal cells. The median layer is composed of muscles and connective tissue elements. There are two sets of muscles—longitudinal and annular. The longitudinal set of muscles are numerous than the annular sets. The muscles are nonstriated. Each muscle is made up of many nonstriated muscle fibres which are ensheathed by a common connective tissue sheath. Each muscle fibre is a flat ribbon-like cell with a conspicuous nucleus. The connective tissue cells present in the middle layer are mostly the amoeboid and vacuolated cells. The ectodermal layer lining the atrium is composed of flat cells.

COELOM AND ATRIUM

Due to the overdevelopment of the atrium or peribranchial cavity, the true coelom in Herdmania is absent except certain doubtful derivatives, like the pericardial cavity, gonad, etc.

Like that of Ascidia, the space between the pharynx and the mantle is occupied by the atrium. The atrium is divided into right and left halves due to the attachment of the pharynx with the mantle on the ventral and dorsal sides. However, both the halves are continuous dorsally and open to the exterior through the atriopore.

LOCOMOTION

Herdmania, in adult stage, is sessile. The visible movement is observed during the contraction of the body for the squirting out of water through the oral and atrial funnels. This movement is caused by three sets of special muscles. These are divided into the (*i*) Oral muscle group, (*ii*) Atrial muscle group and (*iii*) Atrio-oral muscle group. Both the oral and atrial muscle groups surrounding the funnels are formed of annular muscles and the longitudinal muscles. The annular muscles are composed of strong circular muscles and sphincter muscles (oral and atrial sphincters). The longitudinal muscles are more extensively developed than the annular muscles. The atrio-oral muscle group is composed of one muscle band running between the oral and atrial funnels and two pairs of muscles situated, one pair on each side of the neural gland. These muscles extend longitudinally from one funnel to the other. The contraction of the body is caused by the longitudinal muscles while that of the funnels is effected by the annular muscles.

DIGESTIVE AND RESPIRATORY SYSTEMS

The digestive tract starts from the oral funnel. It has a tubular cavity containing the mouth at the basal end. The base of the funnel is provided with a circlet of tentacles. The tentacles are extensively branched delicate structures and form a sort of strainer to prevent the entry of larger particles into the pharyngeal cavity. The tentacles are richly supplied with nerves, the presence of which led many workers to suggest that these are also testing organs. The tentacles are broadly divided into four varieties depending on size. Although the number, size and shape of the tentacles show individual variation, the typical tentacular formula stands as: 8 large (5 mm in length), 8 median (2.5 mm long), 16 small (1.5 mm in length) and 32 minute (0.5 mm long). Each tentacle bears numerous paired lateral branches called the *tentaculets* which also carry small secondary branches. The secondary branches bear tertiary branches.

The mouth leads into a spacious sac-like pharynx or branchial sac which occupies the major part of the body. As stated earlier, the pharynx is enclosed by the atrium except the ventral and dorsal side. The wall of the pharynx is perforated by numerous stigmata. The roof of the pharyngeal cavity is marked by the presence of a thin fold called the *dorsal lamina* which is situated along the middorsal line. The free margin of the dorsal lamina produces 20–30 tentacle-like outgrowths called the *languets*. The dorsal lamina is lined outside by the non-ciliated cells while that of the languets are ciliated. The connective tissue core of both these structures contains blood sinuses. The *endostyle* runs as a shallow longitudinal groove running along the midventral line of the pharynx. It resembles closely that of Ascidia in structure, function and origin. At the anterior end of the pharyngeal cavity there are two pairs of ciliated bands (*peripharyngeal bands*) which are spaced by a *peripharyngeal groove*. The anterior pair of peripharyngeal bands unites to form a complete ring, while the posterior pair is interrupted to become continuous with the dorsal lamina and with the folded margins of the endostyle. Both the peripharyngeal bands and groove are lined by the tall ciliated cells. The inner wall of the pharynx becomes folded longitudinally to increase the surface area. The inner cavity of the pharynx is lined by non-ciliated cells while the cells in the region of the stigmata are tall and ciliated.

The pharynx is supplied by two sets of blood vessels. The inner side of the pharynx is supplied by *internal longitudinal vessels* and the outer side by the *external transverse vessels*. These two types of the vessels are so arranged that they cross one another at right angles. As a consequence, many square areas are produced which are bounded by transverse and longitudinal vessels. Such areas are often designated as the *stigmatic areas*. About 5–6 stigmata are present in each stigmatic area. Many small transverse blood vessels traverse the stigmatic areas.

The pharynx leads into a very short curved tube called the *oesophagus*. The opening of the oesophagus is guarded by two semicircular folds. These folds are produced by the modification of the posterior-most part of the pharynx. The *stomach* is not so much dilated as seen in Ascidia. The stomach leads into the *intestine* which forms a single loop. The distal limb of the loop is called the *rectum* which opens through the *anus* into the atrial funnel.

Digestive glands

Two large unequally developed digestive glands ("Liver") are present in Herdmania. These glands are closely associated with the stomach. The liver is composed of an accumulation of a large number of caeca embedded in a ground substance. This is made up of connective tissue and blood sinuses. The products of the liver are poured into the stomach by eleven independent ducts. Each duct is formed by the union of many ductules coming from the caeca.

The other digestive gland is the *pyloric gland*. It is an extensively branched structure and composed of numerous tubules. This gland remains in close contact with the stomach and intestine. The tubules unite to form a number of ducts which ultimately open into the middle part of the intestine by a single opening. The exact function of the pyloric gland is not properly known. It acts as a pancreas and also as an excretory organ.

The mechanism of food collection, digestion and respiration are similar to those of Ascidia. Only striking difference in the digestive system is the presence of a well-developed liver in Herdmania which is lacking in Ascidia. The digestive enzymes secreted by the distal parts of the liver-tubules, are poured into the stomach. The digestive enzymes are the amylase, protease, lipase, invertase, lactase and maltase. The liver stores carbohydrates in the form of starch. The exact relationship of the liver of Herdmania with that of vertebrates has not been experimentally established.

The respiratory system in Herdmania is more efficient than that of Ascidia. The pharynx is a highly vascular structure and the interstigmatic and intrastigmatic blood vessels help in the exchange of respiratory gases. The presence of internal foldings increase the surface area of the pharynx. Besides the pharynx, the test also acts as an accessory respiratory organ. It is richly supplied with blood vessels and vascular ampullae.

CIRCULATORY SYSTEM

The circulatory system is highly developed in Herdmania. Due to the extensive vascularisation of the test, the circulatory system is modified. The blood contains a few colourless amoeboid and plenty of pigmented corpuscles. Six types of corpuscles are claimed to be present in Herdmania. The pigment present in the corpuscles are either orange or yellowish green or yellow or brown but red colour is absent.

The heart is a cylindrical tube-like structure enclosed by tubular pericardium. The heart is attached to one side of the pericardium by a thin connective tissue bridge. It is situated ventral to the right gonad as an obliquely placed tube about the middle of the endostyle. The heart is a highly contractile tube but the pericardial wall is non-contractile. The wall of the heart is composed of a thin outer striated muscle layer which encloses an epithelial layer. The heart contracts and dilates by the activity of the heart muscles. The wave of contractions of the heart is alternately reversed as seen in other ascidians.

The larger blood vessels have definite wall while the small ones lack definite wall and these are mere sinuses (haemocoel). Originating from the heart, a large vessel extends anteriorly as well as posteriorly below the whole length of the endostyle. This is the strongest vessel in Herdmania and is called the *ventral* or *hypobranchial vessel*. The ventral vessel throughout its course gives paired transverse vessels to the pharynx and a stout *ventral test vessel* to the test. The latter one originates just from the region of origin of the ventral vessel from the heart. Another large blood vessel located dorsal to the dorsal lamina is the *dorsal vessel* which receives *transverse vessels* from the pharynx along its course and anteriorly sends branches to the neural gland. Originating from the dorsal vessels there is a small *branchiovisceral vessel*. This vessel bifurcates into right and left vessels on the respective sides of the pharynx. The left one is the *ventrointestinal vessel* supplying blood to the oesophagus, stomach and left lobe of liver while the *right oesophageal vessel* supplies the right lobe of liver and oesophagus. From the dorsal side of the heart a *cardiovisceral vessel* emerges out. This vessel immediately divides into two branches. One of the branches is the *hepatic vessel* ramifying within the liver and the other vessel immediately bifurcates to form a slender *test vessel* and a stout *oesophageal vessel.* The cardiovisceral vessel, after sending these branches, gives off one dorsal, a median and a ventral vessel. The dorsal branch ends in a ring-like *subtentacular vessel.* It encircles the base of the atrial funnel and sends branches to the wall of the funnel. The median branch ends in the left gonad. The ventral branch divides into the *dorsointestinal vessel* and a *subintestinal test vessel.*

The pharynx and the test are supplied by many blood vessels from different sources. The anterior part of the pharynx is provided with peripharyngeal vessel which originates from the ventral vessel. The internal longitudinal blood vessels of the pharynx originate from the peripharyngeal vessel.

Thus the circulatory system in Herdmania is very well-developed and the course of circulation, like other ascidians, is periodically changed by the reversion of peristalsis. This phenomenon of reversal of peristalsis is not observed in any other animal except certain larval insects.

EXCRETORY SYSTEM

The neural gland in Herdmania is regarded as the excretory organ. It is an oval-shaped gland situated dorsal to the nerve ganglion. But in Ascidia its position is ventral. This gland is composed of branched tubules and many disquamated cells containing dark granules (probably the excretory products) are found in the cavity of the gland. The actual homology of the gland is much disputed. Julin (1893) and Metcalf (1901) regarded this gland to be homologous with the hypophysis of the vertebrates. But Das (1936) strongly inclines to think that the neural gland, at least in Herdmania, is an excretory organ.

NERVOUS SYSTEM

The nervous system, in adult, is represented by an elongated solid nerve ganglion called the 'brain' or cerebral ganglion. It is situated ventral to the neural gland. From the anterior end of the ganglion, three nerves are emerged out to innervate the oral funnel. The nerve ganglion gives off posteriorly two nerves to the artrial funnel.

SENSE ORGANS

. Definite organs of special sense are absent, but several structures function as the sensory receptors. (1) Receptor cells—many receptor cells (receive contact stimuli) are present throughout the test except the vascular areas. (2) The epithelial cells covering the vascular ampullae of the test are tactile receptors. (3) The pigmented spots or *ocelli* located in the margins of the oral and atrial funnels are the photoreceptors. (4) The *oral tentacles* are able to test the water that is drawn in through the oral funnel. (5) The *dorsal tubercle* is regarded to be either an olfactory or gustatory organ. The dorsal tubercle is composed of two conical elevations. Each conical elevation is produced by a conical lobe which becomes spirally coiled. The dorsal tubercle is situated near the junction of the peripharyngeal bands with the dorsal lamina.

REPRODUCTIVE SYSTEM

Herdmania is hermaphrodite. The hermaphroditic gonads consist of two large lobulated bodies. The right gonad is situated on the right side and just dorsal to the heart while the left gonad is lodged within the loop of the intestine. Each gonad is formed of 10–25 lobes. These lobes are arranged in two rows, one on either side of a central axis (see Fig. 2.24C). Two gonoducts run within the central axis. Each gonodal lobe consists of two distinct zones which differ in cellular structure and colouration. The inner zone (*ovarian region*) contains different stages of egg formation while the peripheral zone (*testicular region*) contains spermatogonia, spermatocytes and spermatozoa. Each gonad is thus an *ovotestis.* Each ovarian region of each gonadal lobe is connected with oviduct through a narrow short tubule called the *ovarian ductule.* The *oviduct* opens to the atrial cavity very near to the anus. Similarly the male gonoduct or vas deferens receive a *sperm-ductule* from each testicular region of the gonadal lobe. The vas deferens opens near to the *oviducal aperture.* The number of ovarian ductules and sperm-ductules usually corresponds to the number of gonadal lobes. But the sperm-ductules from two adjacent gonadal lobes may, sometimes, join prior to opening into the vas deferens.

A mature spermatozoon is a minute structure of about 4 micra in length. Each has a *head* capped by an *acrosome*, a *neck* and an extremely elongated straight *tail.* A mature egg measures 0.30 mm in diameter. Like that of Ascidia, the egg is enveloped by membranes which help in floatation. The cytoplasm of the ovum contains a dense mass of yolk material. The nucleus with an excentric nucleolus is situated on one side of the cell-body. This is lined by vitelline membrane which constitutes the wall of the ovum. There are two more layers—the *inner chorion* and *outer chorion*. Many vacuolated outer *follicular cells* are attached to the outer chorion. The space between the outer chorion and inner chorion is filled with the *interchorional fluid*. The space between the inner chorion and the vitelline membrane is filled up with *perivitelline fluid*. There are many inner follicle cells floating in the perivitelline fluid and the rest adhere to the vitelline membrane.

Although, Herdmania is a hermaphroditic animal, self-fertilization is rare, because the ovarian regions mature prior to the testicular regions (protogynous condition). When the gametes become mature, they are expelled out to the sea water. Fertilization is thus external. The developmental sequences and metamorphosis are exactly similar to that of Ascidia already described.

CLASSIFICATION

CLASSIFICATION IN OUTLINE

Subphylum UROCHORDATA OR TUNICATA

CLASS **Ascidiaceae**

Order *Enterogona*, e.g., *Ascidia*, *Ciona*, *Clavelina*.
Order *Pleurogona*, e.g., *Botryllus*, *Molgula*, *Styela*, *Amaroucium*, *Herdmania*.

CLASS **Thaliacea**

Order *Doliolida*, e.g., *Doliolum*, *Dolichinia*.
Order *Pyrosomida*, e.g., *Pyrosoma*.
Order *Salpida*, e.g., *Salpa*.

CLASS **Larvacea or Appedicularia** e.g., *Oikopleura* and *Appedicularia*.

CLASSIFICATION WITH CHARACTERS

The subphylum Urochordata includes a large number of species which exhibit a high degree of biological diversities. The members are classified under three classes, Ascidiacea, Thaliacea and Larvacea or Appendicularia.

CLASS **Ascidiacea**

This class includes typically the bottom-living forms which vary greatly in size and form. The individuals may be solitary or colonial or compound. The adults become usually sessile after undergoing retrogressive metamorphosis, when the notochord, nerve cord and tail are lost. The brain is reduced to a single solid nerve ganglion. The tunic is a permanent structure and is of considerable thickness. The pharynx is large with persistent gill-slits. The atrium opens dorsally by the atriopore. This class has two orders, Enterogona and Pleurogona.

Order *Enterogona*

The body may be divided into two regions. The neural gland is usually situated ventral to the nerve ganglion. Single gonad is present which is located in or behind the intestinal loop. The larva possesses two sense organs. Examples: *Ascidia*, *Ciona*, *Clavelina*, *Phallusia*.

Order *Pleurogona*

The body is undivided. The neural gland is usually located either laterally or dorsally to the nerve ganglion. There are two gonads located in the lateral wall of the mantle. The larva bears only one sense organ. Examples: *Botryllus*, *Molgula*, *Styela*, *Amaroucium*, *Herdmania*.

CLASS **Thaliacea**

This class includes the free-swimming pelagic tunicates inhabiting the warm and temperate seas. The members of this class vary greatly in size. The adult form is devoid of notochord and tail. The tunic is a permanent structure which bears circular muscle bands. The tunic is thin and transparent. The atriopore is located posteriorly. The pharynx is provided with two large or many small stigmata. Distinct alternation of generations is present in the life-cycle.

Order *Doliolida*

The body is barrel-shaped with complete muscle bands forming eight regular rings. The number of gill-slits is variable. Usually a tailed larval stage is present in the life-cycle. Examples: *Doliolum* and *Dolichinia*.

Order *Pyrosomida*

This order includes only one species, *Pyrosoma*. It is present in all oceans from the surface to a considerable depth. It forms a compact tubular colony. The zooids are embedded in the wall. The muscle bands are present at the end of the body. There is no larval stage in the life history. It reproduces by budding.

Order *Salpida*

The body is cylindrical. The muscle bands are incomplete, i.e., the muscle bands do not form complete rings as seen in Doliolum. It is present in coastal to deeper zone of 4500 feet depth. The first gill-slit forms a large opening in adult. The larval stage is lacking. Example: *Salpa.*

CLASS **Larvacea or Appendicularia**

The members of the class are minute free-swimming pelagic forms with a highly developed tail. The tail is supported by notochord and large striped muscle cells. The body is about 5 mm long. The tunic is not persistent, instead each zooid builds a 'house' secreted by the skin. The nerve cord is persistent. The pharynx bears two stigmata which open directly to the exterior. The atrium is lacking. Examples: *Oikopleura* and *Appendicularia.*

COLONY FORMATION IN UROCHORDATES

Colony formation in some urochordates is a very peculiar occurrence. The colony is formed by the budding off of non-separable individuals or zooids from the parent. Ascidians do not form true colonies. The members of the order Enterogona, usually bud off new individuals which are complete by themselves. They may be mechanically connected with the parent body. Some members of the order Pleurogona have individuals that are buried in common investing mass to form a colony. In Botryllus, a few individuals remain embedded in a common tunic. They have separate oral apertures, but their atrial apertures opening into a common cloacal chamber.

The most peculiar type of colonial urochordate is the Pyrosoma. The individuals form a hollow cylinder. The cylinder is closed at one end and the other end is open This opening is guarded by velum which acts as the regulator of the water flow. The oral funnels of the individuals are situated on the outer side and the atrial funnels open into the cavity of the cylinder.

All the zooids originate from a single sexual progenitor by budding. The budded individuals do not separate themselves from the parent body but remain organically connected with one another. Such a phenomenon leads to the formation of colony, a feature not ordinarily encountered in chordates.

HISTORY

Aristotle (384–322 B.C.) described the first simple ascidian, *Tethyum.* Schlosser and Ellis (1756) discovered the compound ascidians. Since then many ascidians have been added to our knowledge upto the early part of the nineteenth century. But the systematic status of the group remains a disputed issue. Lamarck (1816) gave the name of the group, the Tunicata and placed the ascidians between the Radiata and Vermes. Cuvier placed them within Mollusca, but Lamarck isolated the group from the molluscs. Milne Edwards instituted a new class Molluscoidea to include the Brachiopoda, Polyzoa and the Tunicata. All the disputes regarding the systematic position of the group were put to an end when the remarkable memoir entitled, 'Development of a simple ascidian' was published by Kowalvesky in the year 1886. Since then the inclusion of the group under the phylum Chordata is established with a degree of certainty.

AFFINITIES AND SYSTEMATIC POSITION

The systematic status of urochordates has long been an unsettled issue. But the discovery of tadpole larva in the life history has removed all difficulties extant on the field. Prior to its discovery, claims have been put forward to indicate several animal groups as their relatives.

Nonchordate affinities. Entire food shifting and aerating complex in ascidians have close functional parallel with that of sponges and oysters. Other nonchordate features of ascidians are: (1) the presence of larval eyes and otocyst, (2) the habit of budding chain of new zooids, (3) the colonial adaptation of the simple and composite fixed ascidians and (4) the presence of typhlosole in the intestine. But none of these above nonchordate features appears to be convincing to establish the relationship.

Chordate affinities. The inclusion of the ascidians under the phylum Chordata is beyond any question, because the tadpole larva possesses all the basic characteristics of the chordates, viz. gill-slits, notochord and dorsal tubular nerve cord. As stated earlier, occurrence of these three characteristics in the urochordate is the result of their emergence from a common chordate ancestor.

Relationship with Hemichordata. The nearest existing relatives of the urochordates are probably the hemichordates. This particular contention is based on the scientific facts and is supported by having many structural and functional similarities. The similarities are: (1) The structural plan of pharynx with all its accessories are strikingly similar in both. (2) Occurrence of restricted notochord, although the claim of notochordal nature of the buccal diverticulum is quite doubtful in hemichordates. (3) The development of the central part of the nervous system is closely similar. But such a relationship cannot be fully justified because the inclusion of the hemichordates under the phylum Chordata itself remains a debatable issue. The aforesaid similarities can be interpreted as the result of remote phylogenetic relation with the ancestral chordate stock.

Relationship with Cephalochordata. On the basis of adult anatomy of the cephalochordates and the study on the development of the ascidians, the relationship between urochordates and the cephalochordates cannot be denied. The adult forms of both the groups exhibit many structural similarities which are: (1) Similar food concentration mechanism. (2) Presence of velum and velar tentacles. (3) Similarly constructed endostyle and its associated parts. (4) Presence of similar atrial complex.

The ascidian tadpole and the adult cephalochordate also furnish many striking similarities which afford convincing evidence of evolution from a common chordate ancestry. Early developmental stages are so closely similar that the sequences seem to be almost a duplication. The tadpole larva, before degeneration sets in, is similar to cephalochordate in many respects. Besides the basic chordate features, both the forms exhibit the followings semblances: (1) the presence of dorsal and ventral fins, (2) the presence of endostyle and (3) similarities in the atrial complex. Besides the fact, the specialisations of the cephalochordates are exactly in the same direction as seen in the case of urochordates. This coincidence indicates that the cephalochordates have been departed from the main line of chordate evolution. But for the unsegmented organisation in urochordates and for the difference in the developmental history, the above relationship becomes difficult to establish. The common characteristics, particularly in the feeding and aerating mechanisms are due to similar habitat. Other similarities are the result of their remote phylogenetic connection with the stock from which the urochordates and the cephalochordates have descended.

Relationship with Vertebrata. From the standpoint of evolution, the ascidians are related to the vertebrates. The tadpole larva is compared with the larval fish. The neural gland is considered homologous with the hypophysis of vertebrates. It has experimentally been shown that the mammalian gonadotropins stimulate the ascidian neural gland. Various far reaching hypotheses have been based upon the discovery of the tadpole larva in the developmental history of the ascidians. The most remarkable one is to place them in the direct line of the vertebrate ancestry which is fully discussed in the next chapter.

As regards the inclusion of the ascidians under the phylum Chordata, there is little doubt at present, because the tadpole larva is basically a chordate having notochord, dorsal tubular nerve cord and gill-slits. But the degree of degeneration undergone by this group becomes difficult to interprete. Two views exist on this particular issue. The urochordates, according to one view, are extremely degenerated forms and have descended from the ancestors which had all the chordate characters. In the opinions of the others, the ancestors of the urochordates are much lower in the status than any existing chordate, even lower in scale than the cephalochordates and has not yet acquired the distinctive characteristics of the higher forms. The protourochordates arose from the invertebrate chordates which are not far from the ancestor of the cephalochordates. As regards the interrelationships with the urochordates, it can be regarded that the Larvacea are the most primitive forms. The Thaliaceans have derived from the fixed ascidians, not far from the ancestral compound ascidians which gave origin to the Pyrosomida. The composite ascidians are polyphyletic in origin.

FEEDING MECHANISM

Most of the animals move from one place to another in search of food. But in partial or complete sessile animals, this particular function of locomotion is compensated by the development of special structures. Majority of the invertebrate chordates are either sedentary or sessile and they have developed specialised devices to strain off micro-organisms from the water. Isolation of food materials from the water is done by the ciliary and glandular tracts. So the method of feeding is called the ciliary mode of feeding. The pharynx is modified in the invertebrate chordates to perform dual functions: (1) respiration and (2) food collection. In all of them, a constant flow of water current passes into the pharyngeal cavity and goes out through the atriopore.

Structural elements associated with feeding. The pharynx in the invertebrate chordates plays the most spectacular role in straining off the food materials from the incoming water current. For this physiological function, the anatomy of the pharynx and its associated structures become greatly altered. The pharynx includes the portion of the gut from the posterior part of the mouth cavity to the beginning of the oesophagus. Although the pharyngeal apparatus is basically similar in all these forms, some minor differences exist which depend on the degree of sessile habits. The differences of the pharyngeal apparatus in the invertebrate chordates are shown in the Table Chordata 2.

TABLE CHORDATA-2

CONTRASTING FEATURES	BALANOGLOSSUS	ASCIDIA	BRANCHIOSTOMA
1. Shape of pharynx	The pharynx is an elongated structure which is internally divided into two incomplete upper and lower halves by a longitudinal parabranchial ridge. The upper one is called the respiratory portion and the lower part is the digestive chamber.	The pharynx is a sac-like chamber of large dimension. The internal wall of the pharynx is complicated. In a related urochordate, *Herdmania*, the internal cavity is longitudinally folded to increase the surface area.	The pharynx is a large cylindrical and highly compressed chamber. Like that of Ascidia, the pharyngeal cavity is very much complicated.
2. Extension of pharynx.	The pharynx is contained in the branchio-genital region of the trunk.	Extended from the mouth nearly to the base of the body.	Extends nearly the anterior half of the body.
3. Relationship between mouth and pharynx.	The mouth leads into a short buccal tube which opens into the pharynx.	The mouth is situated at the centre of the velum and placed in the posterior end of the oral funnel. The mouth opens into the pharynx.	The mouth is situated at the end of the vestibule which is preceded by the oral hood and buccal cirri. A wheel organ is present in the vestibule. The mouth leads into the pharynx. Like that of Ascidia, the mouth is guarded by velum.
4. Relationship bet- n pharynx and intestine.	The pharynx leads directly into the straight intestine.	The pharynx is communicated with the stomach through a narrow oesophagus.	The pharynx opens into a straight midgut.
5. Mode of attachment of the pharynx.	The pharynx is attached with the body by the dorsal mesenteries.	Only the ventral side of the pharynx is attached with the mantle along the middle line.	Only the dorsal side of the pharynx is united with the body wall.
5. Atrium	Absent.	A special cavity called the atrium or peribranchial cavity encloses the pharynx on all the sides except the ventral one.	The atrium envelopes the pharynx on all the sides except the dorsal. The atriopore is located posteriorly.

Table Chordata-2 (contd.)

CONTRASTING FEATURES	BALANOGLOSSUS	ASCIDIA	BRANCHIOSTOMA
		The atrium opens to the exterior through the atripore situated on one anterolateral side of the body.	
7. Gill-slits	The upper respiratory half is perforated by numerous U-shaped gill-slits which increase with age. Each gill-slit leads into a branchial sac which in turn communicates to the exterior by a gill-pore. In *Balanoglossus misakiensis* the first four branchial sacs fuse to form a common branchial sac opening by a single gill-pore. The gill-bars contain innumerable long vibratile cilia.	The pharynx is pierced on all sides except the line of attachment with the mantle by innumerable vertical stigmata. The stigmata bears series of papillae containing muscles and cilia.	The lateral wall of the pharynx is perforated by obliquely arranged vertical gill-slits. There are two types of gill-slits, the primary and secondary ones. There are about 200 gill-slits which increase with age. Each gill-slit opens directly into the atrium. The tongue-bars are provided with long cilia.
8. Pharyngeal cavity	The cavity is almost uniformly lined by cilia and mucous cells.	The cilia and glandular elements are restricted into definite tracts.	Like that of Ascidia. definite ciliated tracts are also present in Branchiostoma.
9. Hypopharyngeal tract.	No such structure is present.	A highly developed endostyle is present inside the ventral side of the pharynx. Endostyle acts as a fly-paper. The endostyle has two rows of mucous cells separated by rows of ciliated cells. A group of median cells with extremely elongated cilia is present at the middle.	Endostyle consisting of tracts of ciliated cells alternating with mucus-secreting cells is present.
10. Hyperpharyngeal tract.	Absent	On the midventral line of the pharyngeal cavity, i.e., just opposite to the endostyle, there lies the dorsal lamina from which hangs a number of curved bodies called the languets.	A median groove called the epipharyngeal or hyperpharyngeal groove is present opposite to the endostyle.
11. Peripharyngeal ciliated tracts.	Absent	The dorsal lamina and the endostyle are joined by the peripharyngeal ciliary bands.	The epipharyngeal groove and the endostyle are connected anteriorly by peripharyngeal ciliated tracts.

Mechanism of food concentration. The food of the invertebrate chordates comprises of micro-organisms which are suspended in the sea water in a very dilute condition. The food particles are to be filtered out by removing the excess of water from the pharyngeal cavity. This phenomenon is effectively done by an efficient mechanism of food concentration.

The cilia of the gill-bars in the pharynx beat synchronously and by their powerful movement a current of water is produced which after entering the mouth passes towards the pharynx. The velar tentacles in urochordates resist the entry of big particles which are undigestable. The same function is performed by the buccal cirri in the cephalochordates. In cephalochordates the wheel organ creates a vortex of water and focus it towards the mouth. Before entering the pharyngeal cavity the velar tentacles sieve off sand grains and other unwanted particles. Enormous quantity of water containing the food enter into the pharyngeal cavity and most of the water goes out to the atrium in urochordates and cephalochordates and directly to the outside in hemichordates through the gill-slits or their derivatives. In hemichordates, the food particles along with the sand grains are entangled by the mucus secreted from the glands present in the mouth cavity and passes through the pharynx into the intestinal cavity. The mucus secreted by the proboscis entangled the sand and other food particles. The mucus coated food particles are pushed directly into the mouth by the ciliary action. This transit is assisted by the ciliary beatings of the ciliated strips so that the food matters are driven towards the intestine. Digestion occurs in the intestine and the sand grains are eliminated in the form of castings.

In urochordates and cephalochordates the endostyle entangles the food by its viscous secretion of mucus. The cilia of the endostyle transform the food into a mucous rope which is driven forward towards the peripharyngeal groove where from it travels backwards through the hyperpharyngeal groove in cephalochordates and the dorsal lamina in case of urochordates into the intestine by the ciliary action. In the intestine the food is digested and the undigested products are discharged through the anus.

The most important feature of the ciliary feeding in invertebrate chordates is that the selection and filtration of the food are done by physical means. This method of feeding is a variant of the general process observed in other forms where the sorting of the food particles is done inside the pharyngeal cavity. The presence of numerous gill-slits is an adaptive feature which facilitate the elimination of excess of water from the pharyngeal cavity and also help in the process of gaseous exchange.

The pharynx of the invertebrate chordates has been specialised and elaborated as a food concentrating apparatus in addition to its normal respiratory function. This apparatus shows close similarity in the different invertebrate chordates. The degree of specialisation of the pharynx in these forms bears a distinct ratio to their sedentary habits. The close similarities in the structure and function of the pharyngeal apparatus are suggestive of the original habit of the earliest ancestral chordates from which they have evolved.

INTERESTING INVERTEBRATE CHORDATES

The inveretebrate chordates include a large number of diverse forms. Besides the foregoing description of a few typical representatives, a brief account of some peculiar forms are given below.

Saccoglossus

Saccoglossus (= ***Dolichoglossus***) is a typical enteropneust and is constructed on the basic enteropneustan plan (Fig. 2.22A). Saccoglossus bears some peculiar individual features. It excavates spiral burrow for living. *Saccoglossus pygmaeus* is the smallest enteropneust measuring about 2-3 cm long. The proboscis is exceptionally elongated and slender in this genus. The posterior fold of the collar hangs like operculum over the anterior end of the trunk. The glandular collar epidermis exhibits three distinct histological regions. The oesophagus opens to the exterior through four to six pairs of dorsal canals. The dorsal proboscis nerve cord expands into a fan-shaped area in the posterior part of the proboscis.

Cephalodiscus

Cephalodiscus is a typical genus under the class Pterobranchia. Many animals live in association and inhabit a branched upright tubes secreted by them. The tubes are called the *coenecium* of unknown composition. Foreign particles like sand grains, broken molluscan shells and spicules of sponges adhere to the coenecium. Each tube is occupied by an individual or zooid. All the tubes are fixed permanently on the substratum. The body is divided into three regions. The proboscis is represented by a flexible disc-like structure which is tilted as the upper lip to conceal the mouth. There are two proboscis pores in Cephalodiscus. The collar bears four to nine pair of arms. Each arm contains two rows of tentacles which are tipped by glandular knobs. The trunk is subdivided into two portions; an anterior sacciform part containing the alimentary canal and gonads and a posterior slender part for attachment with the tube. The alimentary canal is U-shaped with the mouth and anus located on the same side of the body. A single pair of gill-slits is present. Tongue-bars and skeletal supports are absent. The gonads are two in each zooid and are symmetrically placed in the anterodorsal part of the trunk. Asexual reproduction by budding is common. Buds are produced in a localised budding zone near the stalk. Each zooid may possess one to fourteen buds at a time. All the zooids in an aggregation have arisen from a single sexual progenitor by the process of budding.

Rhabdopleura

Rhabdopleura is a colonial pterobranch (see Fig. 2.23). The zooids secrete small, erect and ring-like tubes of 6–7 mm in height. All the tubes are joined basally by a ***black stolon***. This stolon also connects all the zooids of the colony. The zooids resemble

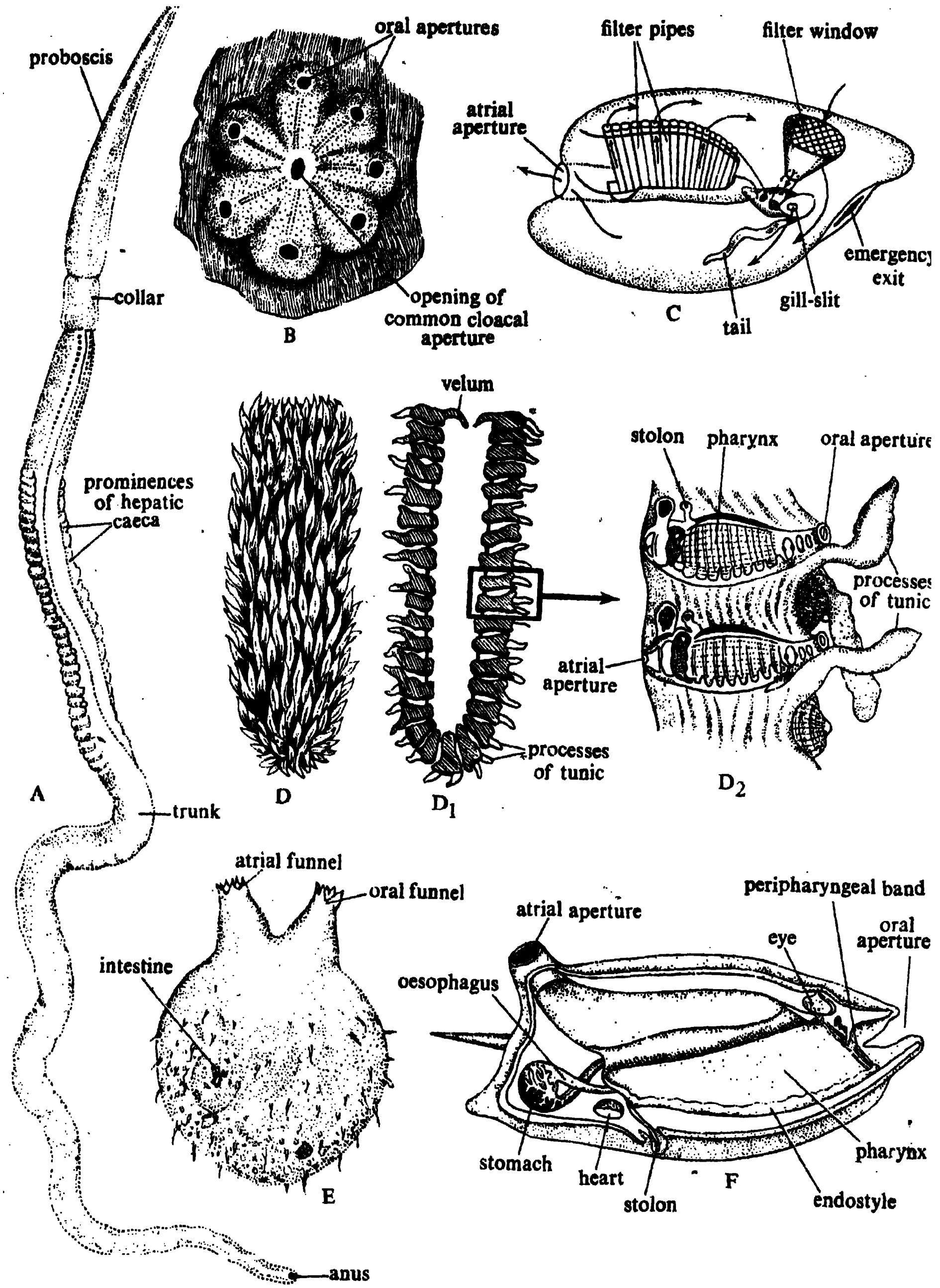

proboscis
collar
prominences of hepatic caeca
A
trunk
anus
oral apertures
opening of common cloacal aperture
B
filter pipes
filter window
atrial aperture
emergenc exit
gill-slit
tail
C
velum
D
D1
processes of tunic
atrial aperture
stolon
pharynx
oral apertur
processe of tunic
D2
atrial funnel
oral funnel
intestine
E
atrial aperture
peripharyngeal band
eye
oral aperture
oesophagus
pharynx
stomach
heart
stolon
endostyle
F

Fig. 2.22. Some invertebrate chordates. A. *Saccoglossus*. B. *Botryllus*. C. *Oikopleura*. D. A colony of *Pyrosoma*. D$_1$. Longitudinal section of *Pyrosoma*. D$_2$. A portion of the wall of the colony is enlarged to show the disposition of two zooids. E. *Molgula*. F. Longitudinal sectional view of *Salpa*.

closely those of Cephalodiscus except that the zooids are very small and measuring below one millimeter in length. Only one pair of arms is present in the collar. The gill-slits are totally absent. Single gonad is present and is situated on the right side of the trunk.

Atubaria

Atubaria is a solitary pterobranch closely related to Cephalodiscus. The coenccium is absent. The body is about 1–5 mm long. The collar bears four pair of tentaculated *arms*. The distal ends of the second pair of arms are devoid of tentacles and rod-like in appearance. The stalk lacks the adhesive tips and the Atubaria clings on the hydroid colonies by its stalk. The pharynx is perforated by a pair of gill-slits.

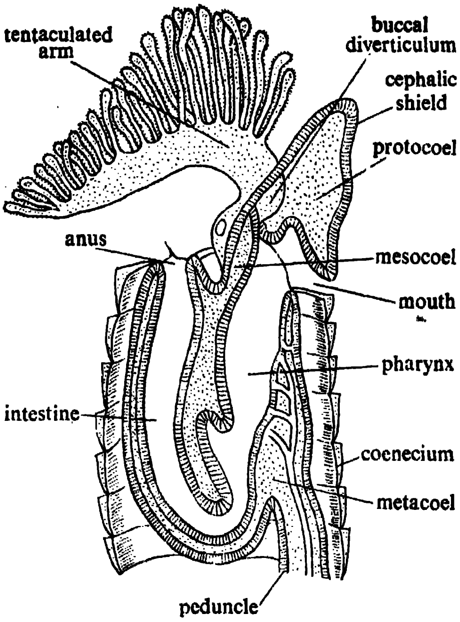


Fig. 2.23. Longitudinal section of *Rhabdopleura*.

Salpa

Salpa is a typical pelagic tunicate resembling superficially the Doliolum, but differs in details. It has a fusiform body which is covered over by a thin and transparent test. The muscle bands form incomplete rings (Hemimyaria) in Salpa. The mouth and anus are located at the two ends of the body (Fig. 2.22F). The life-history involves the alternation of generations. The sexual form produces a single egg which develops within the mother and nourished by a diffused placenta. The tadpole larva is absent. The developing embryo becomes the 'Nurse Zooid' or 'Oozooid' which produces a long chain-like blastozooids. The blastozooids are set free in course of time.

Doliolum

The anatomical organisation of Doliolum is basically similar to other ascidians but it differs in certain points. The solitary sexual form (Gonozooid) is barrel-shaped and is provided with seven or eight muscle bands that encircle the body completely (Cyclomyaria). By the contraction of these muscle bands, Doliolum swims in water. The oral and atrial funnels become elaborated into ten to twelve lobes at the two extermities of the body (Fig. 2.24A). The test is very thin, transparent and noncellular. The oral funnel opens into a spacious pharynx, the wall of which is perforated by the dorsal and ventral rows of stigmata. The dorsal lamina is absent. But the endostyle and the peripharyngeal ciliated bands are present. The oesophagus leads into a small stomach. The intestine is very short and is partially U-shaped. The dorsal side is comparatively extensive. The dorsal neural ganglion and subneural gland are located anteriorly. The neural ganglion gives nerves to the eight muscle bands. The heart is located posterior to the endostyle. The sexes are united. The free-swimming Doliolum has originated from sessile ancestor. The ovary and testis are located ventral to the body. The eggs are liberated in the cloacal chamber and finally expelled to the sea water. Fertilization is external.

Development and life-history

Cleavage is holoblastic. Gastrulation occurs by embolic fashion. A tailed tadpole larva emerges out after gastrulation. The tailed larva represents the asexual stage. (Fig. 2.24 B). The tail is comparatively short and acts as the locomotory organ. Metamorphosis of the tadpole larva starts without the larva being fixed to the substratum. The process of metamorphosis is shown in Figure 2.24. The tail is gradually lost and the tadpole larva is transformed into a 'Nurse' or 'Oozooid' having a codophore on the posterodorsal side and a ventral stolon. Numerous buds are developed on the posterodorsal side and a ventral stolon. The buds have the power of migration and become localised on the codophore in rows. The codophore becomes elongated and most of the buds transform into the zooids. The zooids present on the codophore are divided into two major types, the lateral and median zooids. The lateral zooids are converted into the trophozooids. But some of the median zooids develop into the phorozooids. On the stalk of the phorozooids a few buds remain attached which ultimately develop into the gonozooids. So in the life of Doliolum, there are three types of zooids. The biology of the zooids are:

(1) TROPHOZOOIDS—These sessile zooids are nutritive and respiratory in functions. These are sterile and remain attached with parent. (2) PHOROZOOIDS—These are also sterile, but are set free in water. (3) GONOZOOIDS—The gonozooids are sexual forms, which are carried and nursed by the phorozooids until the sexual maturity is attained. After attaining sexual maturity, the gonozooids become detached from the phorozooids and lead independent free-swimming life.

Molgula

Molgula is a very important European monoascidian (Fig. 2.22E). It is built on the typical ascidian plan. The body is either ovoid or spherical in shape and measures about 3–8 cm in diameter. Both the oral and atrial funnels are large and are produced into six lobes. The test contains fibrils and sand grains adhere to the surface of the test. The stigmata are spiral. The internal cavity of the pharynx usually shows seven longitudinal folds. A single large renal sac is present in the right side of the body. Two club-shaped gonads, one on each side of the body, are present. Molgula is oviparous and the development is either direct or indirect. In some species of the genus, like *Molgula arenosa*, *Molgula occulta*, *Molgula manhattensis*, the development occurs without any larval stage, while others are larviparous.

Pyrosoma

Pyrosoma is colonial pelagic tunicate (Fig. 2.22D). The colony consists of many zooids or individuals which are associated together to form an elongated hollow colony. One end of the colony is closed and the other end is open. The open end serves as the common 'cloaca' for all the zooids. This aperture of the colony is guarded by a velum (Fig. 2.22D$_1$).

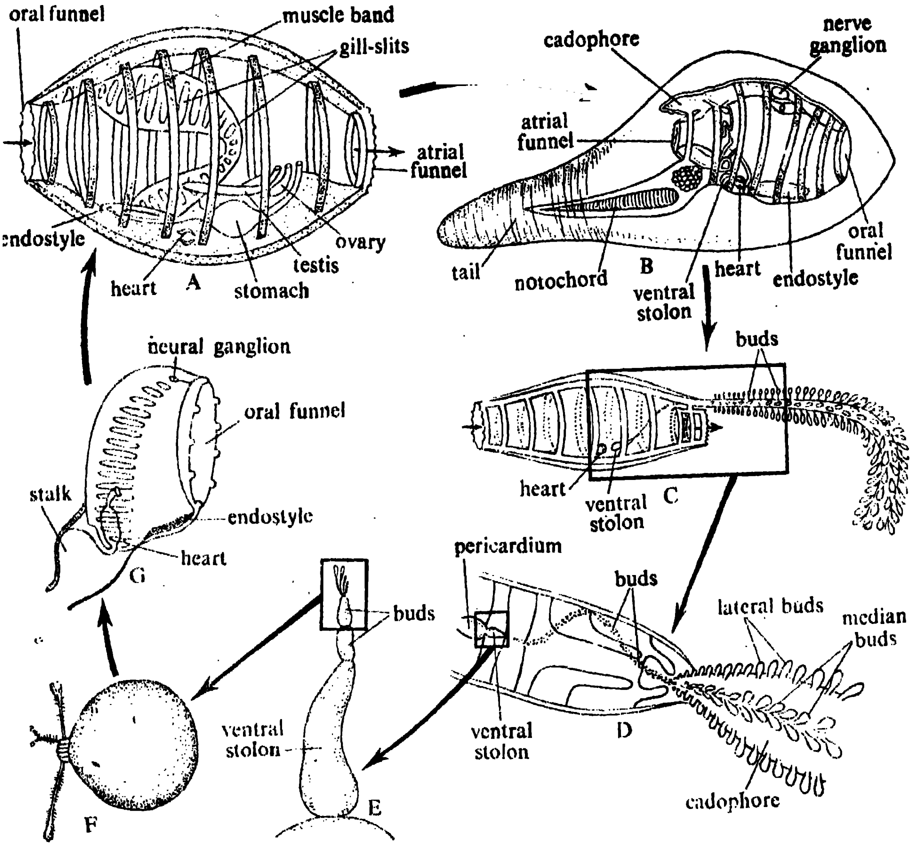

oral funnel
muscle band
gill-slits
atrial funnel
endostyle
ovary
testis
heart
A
stomach
cadophore
nerve ganglion
atrial funnel
oral funnel
tail
notochord
B
ventral stolon
heart
endostyle
neural ganglion
oral funnel
stalk
endostyle
heart
G
buds
heart
ventral stolon
C
pericardium
buds
buds
lateral buds
median buds
ventral stolon
ventral stolon
D
cadophore
E
F

Fig. 2.24. Life-cycle of *Doliolum*.
A. A Gonozooid. B. Advanced tailed larva. C. Structure of "nurse" stage. D. Posterior portion of the asexual stage showing the migratory path of the buds from the ventral stolon to the codophore. E. Showing the process of segmentation of stolon. F. A young migrating bud. G. Structure of a Trophozooid developed from one the buds of the lateral row (after various sources),

The opening and closure of the aperture is controlled by the velum and thus regulate the water flow. The zooids are arranged in an organised fashion in the wall of the colony. The oral ends open to the outside and the atriopores open into the hollow of the colony (Fig. 2.22D_2). The zooids are of asexual types and are capable of budding. The colony is brilliantly phosphorescent. The light is emitted by the photogenic organs situated on each side of the pharynx. These organs are composed of photogenic cells. The photogenic cells contain numerous curved inclusions in the cytoplasm. Actual nature of such inclusions is not known although claims have been made by some workers that these are possibly some forms of symbiotic luminescent bacteria. The light is not produced at all the times, but only when the animals are stimulated even by the waves of a rough sea.

Botryllus

Botryllus is a compound ascidian in which the individuals are embedded in a common gelatinous test (Fig. 2.22B). The colony is star-shaped and remains attached on the hard surface of the bottom. The individuals are arranged in a radiating manner around a common cloacal chamber. Each zooid has a separate oral funnel at the ends of the radii but their atrial apertures lead into a common cloacal chamber situated at the centre of the colony. Each individual is built on the typical ascidian plan.

Oikopleura

Oikopleura is a tiny, neotenous free-swimming and pelagic tunicate. It has a rounded body and a tail-like appendage attached to the posterior end of the body. The tail is supported by the notochord and also contains the nerve cord and muscles. The muscles do not exhibit metamerism. The tail has a wide and continuous fin. The tail is an efficient locomotor organ and remains attached with the body by a ball-and-socket mechanism.

The test is absent and each individual makes a 'house' out of its test to envelope itself. The house is secreted by the 'oikoplastic epithelium' a special part of the skin. A constant water current is maintained by the activity of the tail. The water current enters into the house by a pair of filtering windows on the posterior side and passes out through a system of filtering pipes in front of the mouth (Fig. 2.22C). Minute ciliates or flagellates are caught in the filtering pipes and are sucked by the mouth. The pharynx bears two gill-slits, endostyle and peripharyngeal bands. The alimentary canal is U-shaped. A large hermaphroditic gland is present in the posterior end of the trunk.

SUMMARY

1. The chordates present different gradations of structural organisation from the simple to complex.

2. The hemichordates, urochordates and cephalochordates are the primitive members of the phylum Chordata. These animals are collectively called the invertebrate chordates or protochordates or lower chordates.

3. The rest of the chordates, besides the invertebrate chordates, are called the vertebrates or craniates. The vertebrates are characterised by having vertebral column and skull, which are lacking in the invertebrates chordates.

4. The invertebrate chordates constitute a very small group of animals and at the same time they form a transitional group between the invertebrates and the vertebrates. The invertebrate chordates are placed under three subphyla, Cephalochordata, Hemichordata and Urochordata.

5. The Cephalochordata possesses two genera, *Branchiostoma* and *Asymmetron*. Both the forms exhibit a fair picture of typical chordate and fulfil the theoretical definition of the Chordata.

6. The Hemichordata represents a very interesting and primitive group of chordates being examplified by *Balanoglossus*, *Cephalodiscus*, *Rhabdopleura*, *Planctosphaera* and many others. Because of their peculiar anatomical construction, the systematic status of the whole group remains a perennial controversial problem.

7. The subphylum Urochordata is a unique group consisting of members showing high degree of variation in structure, habit and habitat. Urochordates exhibit certain exceptions to the chordate organisation, like the retrogressive metamorphosis, alternation of generations and formation of colony by the process of budding from a primary sexual progenitor. All the urochordates are included under three classes: Ascidiacea, Thaliacea and Larvacea. The typical examples are: *Ciona*, *Herdmania*, *Ascidia*, *Botryllus*, *Doliolum*, *Salpa*, etc.

8. All the invertebrate chordates are exclusively marine animals. Most of them are sessile in adult stage and feed upon micro-organisms that are collected by the ciliary action. The pharynx in all of them become highly specialised for dual functions: (*i*) respiration and (*ii*) food collection.

CHAPTER 3

Phylum Chordata—Vertebrates

The vertebrates constitute the main subdivision of the phylum Chordata. All the vertebrates are placed under the subphylum Vertebrata or Craniata. In addition to the basic chordate features, the vertebrates possess many specialised characteristics that distinguish them from the invertebrate chordates and invertebrates. The main difference lies in the position of the nerve cord (Fig. 3.1).

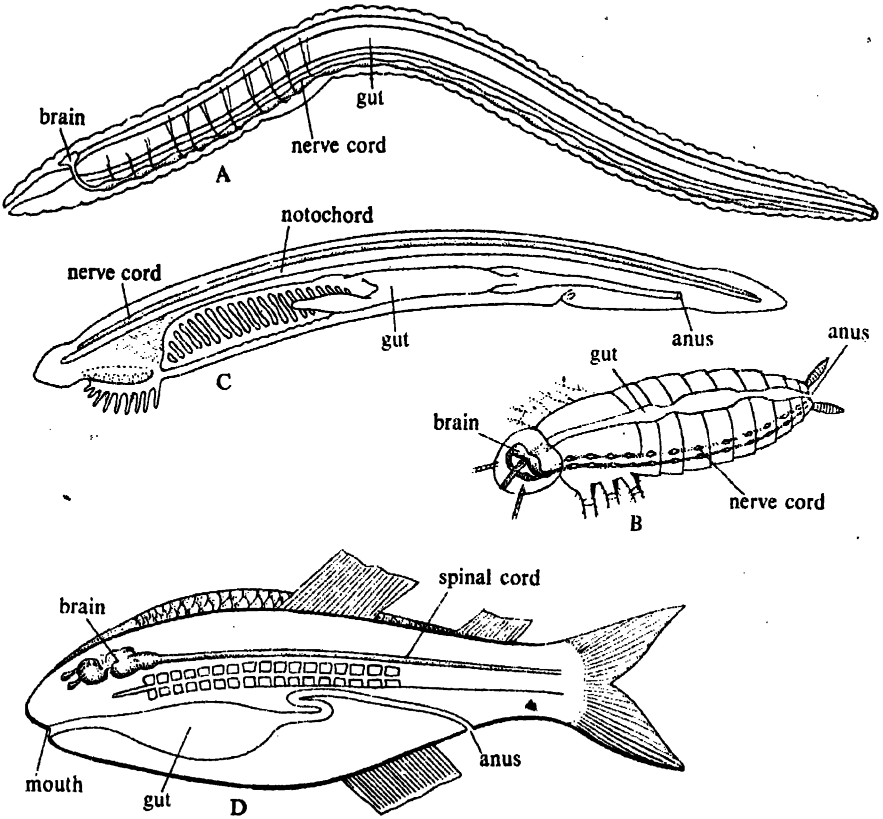


Fig. 3.1. Showing the contrasting position of the nerve cord in an earthworm (A), a cockroach (B), a cephalochordate (C) and a vertebrate (D).

IMPORTANT FEATURES

The diagnostic features of the subphylum Vertebrata are many and it is a difficult to give an exhaustive account of all the characteristics. To name a few, these are: (1) All vertebrates have both internal and external skeletal systems. (2) The presence of vertebral column is significant, because the group gets its name from this structure. The vertebral column is present in a rudimentary condition in Cyclostomata, it is well-formed in higher vertebrates being composed of segmental bony or cartilaginous rings called the vertebrae. The vertebrae are articulated with one another by movable joints. (3) A distinct cranium or brain-case is present to house the brain. Possession of cranium has given another name for the group as the Craniata. The cranium is formed by the fusion of several flat cartilaginous plates around the brain called the *chondrocranium*. By the coalescence of the extra bones and subsequent ossification, the simple chondrocranium has converted into a very complex skull. (4) All vertebrates have a well-developed head, i.e., cephalisation is well-marked. (5) The anterior part of the nerve tube becomes specialised to form an elaborate brain. The brain is associated with some special sense organs like ear, nose and eye. (6) In all vertebrates, a dorsal and a ventral pair of nerve root are given out in each segment from the spinal cord. These dorsal and ventral roots remain separate in lower vertebrates like cyclostomes, but in higher forms these two roots unite to form a common spinal nerve. The ventral nerve is efferent or motor in nature because it carries the impulses from the central nervous system to the effector organs. The dorsal nerve is of mixed type, i.e., it conveys mainly the impulses from the sensory neurones to the central nervous system while a few fibres are motor in function. The dorsal nerve bears a swelling called the *spinal ganglion*. (7) Paired lateral appendages (fins or limbs) are present which help in locomotion. Paired appendages occur universally in the vertebrates except the cyclostomes and some secondarily degenerated forms. (8) The circulatory system comprises of a specialised ventral heart (having at least three chambers), distinct blood vessels and red blood corpuscles containing haemoglobin. Hepatic portal system is present in all vertebrates which constitute a specialised part of the venous system carrying blood from the intestine to the heart via the liver. (9) A post anal tail is mostly present. The tail is regarded as the prolongation of the posterior part of the trunk behind the anus. It lacks the coelomic extension. (10) The excretory system is made up of the mesodermal kidneys which regulate the osmotic pressure and also excrete the nitrogenous wastes from the body. (11) Endocrine glands, secreting the hormones, are present. The hormones coordinate mostly the functional activities of the internal organs.

INVERTEBRATE CHORDATES *versus* VERTEBRATES

As already mentioned in the Chapter-2, the cephalochordates, hemichordates and urochordates are designated as the Invertebrate chordates and the rest of the chordates are called the Vertebrates. The invertebrate chordates and vertebrates have a similar fundamental body construction. Because of this fact these two groups are included under a common phylum. Despite of the resemblances these two groups exhibit certain contrasting features which are tabulated in Table Chordata-3.

TABLE CHORDATA–3

CONTRASTING FEATURES	INVERTEBRATE CHORDATES	VERTEBRATES
1. Notochord	It is an endodermal derivative and develops directly from wall of the archenteron. In hemichordates, this structure is of doubtful nature, in urochordates the notochord is restricted mostly in the larval phase, but in cephalochordates it is persistent in adult.	It develops from the embryonic mesoderm and originates indirectly from wall of the archenteron. The notochord is usually present in the early stages, but in adult it is partially or wholly replaced by the vertebral column.
2. Neural tube	Fusion of the lips of the medullary groove commences from the posterior to the anterior end.	Fusion starts from the anterior to the posterior end. The anterior part becomes the brain and the posterior portion remains as the spinal cord.

TABLE CHORDATA-3 (contd.)

CONTRASTING FEATURES	INVERTEBRATE CHORDATES	VERTEBRATES
3. Neural crest cells	Absent.	Present. The neural tube formation is always associated with the detachment of neural crest cells from the two dorso-lateral sides of the neural tube. The neural crest cells form pigment cells, cartilage and some neurons.
4. Origin of Mesoderm.	Mostly enterocoelic in origin.	Partly enterocoelic in origin.
5. Path of entry of sperm.	Through the vegetal pole of the egg, i.e., from the end opposite to the animal pole.	Through the animal pole, i.e., the end of the egg from which the polar bodies come out.
6. Atrium	Present except the hemichordates. It is a special cavity formed by the involution of the body wall. The atrium surrounds the pharynx (hence also known as peribranchial cavity) and communicates with the exterior through the atriopore.	No such cavity is present in the body.

ORIGIN OF VERTEBRATES

Since the inception of the evolutionary concept that the living organisms transmutate through ages, the question of searching the ancestry of the vertebrates has become a central problem in Biology. Extensive works have been done on this particular problem. The greatest difficulty confronting the workers on this line is the lack of good fossil records of their earlier representatives. In the early phases of the evolutionary history, many invertebrates have been brought to the forefront of the vertebrate evolution. It will not be an exaggeration to speak out that almost all the invertebrate phyla has been suggested to hold the key of vertebrate evolution. But the recent inclinations do not accept the idea of derivation of the vertebrates directly from any specialised adult invertebrate. The dynamic larval stage of some invertebrate forms are claimed to be the possible progenitor of the early chordates which have evolved into the higher forms.

In the present discussion on the origin of vertebrates, all the views extant on this topic have been reviewed. Special emphasis has been given to the recent ideas and the older views have been mentioned only as a piece of historical importance. All the interpretations and arguments have been focussed into the perspective that the invertebrate chordates, originating from some invertebrate source, have given the origin of the vertebrates. The most logical evolutionary trend will be as follows:

INVERTEBRATES→INVERTEBRATE CHORDATES→VERTEBRATES

BIOLOGICAL ORGANISASION

The chordates, as already been discussed, constitute a very large group which includes the invertebrate chordates and the vertebrates. They are characterised by having some identifying features. These features are again repeated to draw parallelism between the vertebrates and the invertebrates in the phylogenetic discussion of the vertebrates. These features are: (1) Body is bilaterally symmetrical. (2) A dorsal tubular nerve cord is present. The anterior part becomes specialised into a brain in the vertebrates. (3) Notochord is present at least in any stage of life-history. (4) The pharynx is perforated by gill-slits. (5) The coelom is enterocoelous in origin. (6) Cephalisation is well-marked. (7) Metamerism is present. (8) A pulsating organ or heart is present in the ventral side of the body.

In search of Ancestry

Similarities existing between some invertebrates and the chordates have led to the enunciation of several theories on the origin of vertebrates. All these theories postulate the origin of vertebrates either directly from some invertebrate source or through the intermediate pathway of the invertebrate chordates.

COELENTERATE THEORY

Masterman (1897) advocated that the bilateral symmetry and the triploblastic condition of the earlier stages of *Branchiostoma* have been derived from some round coelenterates. Such an idea yielded no solution to the problem. The coelenterates stand at a very lower level of metazoan grade of organisation and the attempt to advocate the emergence of the chordates directly from such a lowly organised group seems to be unjustified.

NEMERTEAN WORM THEORY

The idea of the origin of the chordates from the nemertean worm was advanced by Hubrecht in the year 1887. He put forward the following arguments in support of his contention. These are: (1) The long proboscis with its sheath in nemertean worm can be regarded as the primal source of the notochord. (2) The lateral blood vessels of the nemertean worm have shifted their positions to become the dorsal and ventral vessels of the chordates. (3) In nemertean worm, the nervous system forms eight longitudinal cords. Hubrecht and Kofoid have suggested the origin of a dorsal nerve tube at the expense of the lateral and ventral nerve cords. (4) Few apertures in the nemertean worm are compared with the gill-slits. (5) The mode of development of the photosensitive cells are similar.

All the points of homology cannot be proved by scientific studies. Because of the lack of evidences and of the existence of wide structural diversities, the nemertean worm concept on the origin of chordate cannot be approved.

PHORONIS THEORY

Masterman (1897) tried to relate the phoronids with the chordates on a phylogenetic ground. The theory was based on the similarities existing between the Actinotrocha larva of *Phoronis* and the Tornaria larva. The most important evidence comes from the disposition of coelom in the two larvae. A pair of gastric diverticula opening into the anterior end of the stomach is homologised by Masterman with the notochord. A septum separating the mesocoel and metacoel is present in Phoronis and Balanoglossus. The tentacular crown of Phoronis resembles the tentaculated arms of Cephalodiscus. The proboscis pore of Balanoglossus is comparable to the water pore of Phoronis.

All the above observations of Masterman have not been corroborated by anatomical evidences. The similarity on the disposition of the coelom can be interpreted as due to the consequence of common remote ancestry of all the Deuterostomous phyla. So the question of holding the ancestral position of the chordates cannot be justified.

ANNELID THEORY

The concept of the annelid ancestry of the chordates was mainly sponsored by Dohrn (1875), Semper (1876) and Minot (1897). They hold the view that the primitive chordates have been evolved from the annelids, typified by the earthworm and some marine worms. The vertebrates have evolved directly from the primitive chordates. The theory was based on the following grounds: (1) Both the groups have bilaterally symmetrical and metamerically segmented body. (2) The parapodia of annelids are comparable with the paired appendages of the vertebrates. (3) Well-developed coelom is present in both the groups. (4) Presence of nerve cord, although differing in disposition. (5) Presence of segmental excretory organs. (6) Presence of longitudinal blood vessels and red coloured blood. (7) As the disposition of the nerve cord and the direction of the blood flow through the blood vessels in annelids are diametrically opposite to that of the chordates, the workers advanced the idea that if the position of the annelid is reversed, the worm is assumed to have turned over to become a chordate (Fig. 3.2).

But the annelid origin of chordates is not convincing because fundamentally a chordate cannot be compared with the annelids. The nature and the disposition of the nerve cord in annelids are quite different. In annelids the nerve cord is a solid structure and occupies a midventral position. But in chordates the nerve cord is a mid-dorsally placed hollow tube. The nature of segmentation is also different. The segmentation in annelids shows the complete division of the body into rings, whereas in chordates only the myotomal region is segmented. In the circulatory system of annelid, the direction of blood flow through the longitudinal blood vessels is just reversed and the haemoglobin remains dissolved in the plasma. In the chordates, the haemoglobin is contained in the R.B.C. The parapodia of annelids are in no way homologous to the paired appendages of the vertebrates. The most important difficulty to support the annelid origin lies in the presence of notochord in the chordates, although attempts have been made to homologise the 'Faserstrang' (a bundle of fibres extending along the nerve cord) with the notochord. The developmental history of the annelids also differs in a number of features. The segmentation of annelids follows a spiral fashion, while in chordates the cleavage plane is radial or irregular. The mode of formation of coelom is different. In annelids the coelom is schizocoelic in origin, while in the chordates it is enterocoelic.

Considering all these contrasting features, the phylogenetic relationship between the annelids and the chordates cannot be established. All the alleged points of homology are mostly speculative and have no solid basis to establish the relationship.

INSECT THEORY

Hilaire (1818) propounded the idea that the vertebrates might have been derived directly from the insects. He put forward the following evidences in support of his idea. These are: (1) The segmented body rings of insect are the precursors of the vertebral column. (2) The legs of the insects have in course of time form the ribs of the vertebrates. (3) The tergum of insect can be compared with the dorsal plate of primitive fishes. (4) Cephalisation is comparable. (5) Hilaire put forward the notion that if an insect made completely overturned, it portrays the entire vertebrate organisation.

This particular concept is not acceptable, because the points of resemblances are mostly imaginary. The insect theory gets a very little recognisation. Insects constitute a very specialised group of invertebrates and the emergence of vertebrates from such a well formed organisms seems to be unjustified. The whole of the developmental events of vertebrates differ greatly from that of insects.

ARACHNID THEORY

Attempts have been made to prove the process of descent of the vertebrates from some primitive arachnids. The theory was established by Patten and Gaskell. They have taken the ostracoderms as the typical representative of the primitive vertebrates and have set aside the *Branchiostoma* and other invertebrate chordates from the picture. *Limulus* is regarded as the primitive member of the Arachnida. It shows structural relationships with Eurypterids (heavily armoured fossil arachnids of the Cambrian to Silurian periods) and the

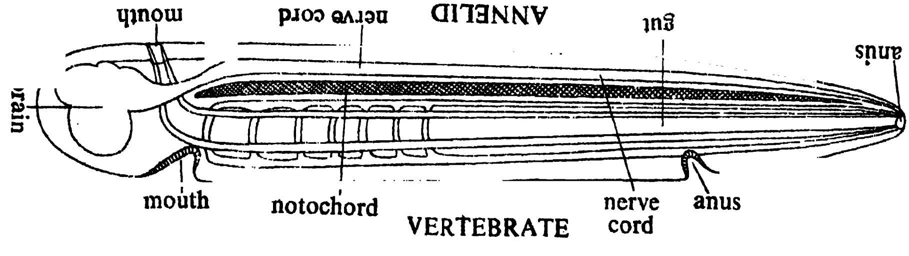


Fig. 3.2. Diagrammatic representation of the supposed conversion of an annelid into a vertebrate (after Dodson).

Eurypterids in turn resemble the Cephalaspids (ostracoderms) of the Devonian period. The probable line of ancestry is as follows:

LIMULUS→EURYPTERIDS→OSTRACODERMS

Patten (1912) wanted to show striking similarities between the heart and the arterial system of Limulus and the vertebrates. The fused cephalothoracic ganglionic mass of arachnid is comparable to the brain and cranial nerves of vertebrates. The 'endocranium' (sternum which protects the central ganglionic nerve complex) of Limulus resembles with the primitive vertebrate cranium. The special sense organs, specially the eyes are comparable. Gaskell (1908) has carried the theory to extremes by assuming that the original digestive system of arachnid has been converted into the nervous system of the vertebrates and the digestive system has been formed anew. The Eurypterids and the ostracoderms have many superficial similarities, particularly in the general arrangement of the plates and head shield.

In spite of all efforts to execute the idea of the origin of the vertebrates from the arachnids, Patten and Gaskell have failed to advance any solution to the problem. The theory is supported by a large body of evidences and the arachnid theory of the origin of vertebrates has some historical value.

ECHINODERM THEORY

Of all the theories discussed so far, the Echinoderm theory on the origin of chordates is most convincing. Many investigators have put forward the following evidences from various sources to establish the view that the chordates have originated from the echinoderms.

Anatomical evidences: The most important anatomical similarity lies in the presence of mesodermal skeleton in both the echinoderms and chordates. The nervous system in hemichordates resembles very closely with that of the echinoderms. In both the cases the nervous layer is present at the basal part of the epidermis.

Embryological evidences. The Tornaria larva of *Balanoglossus* and the larvae of echinodermata exhibit close similarity (Fig. 3.3). Because of the semblances, Johannes Muller and Bateson suggested that the Tornaria larva and the Dipleurula larva have evolved from a common ancestral source. The common features are: (1) The body is minute and transparent. (2) Both have a dorsal pore. (3) Almost identical twisted external ciliated bands are present. (4) Formation and disposition of the coelom are similar. (5) Both are free-swimming forms. (6) Body is bilaterally symmetrical. But the presence of apical plate with eye spots in Tornaria larva raises the doubt. The probable line of ancestry is suggested but further evidences are required to establish the fact. To put more emphasis on the relationship between the echinoderms and the chordates, Garstang and de Beer have added more weight to the ancestry of the chordates from the echinoderm larva. They proposed the Neotenous Larva Theory. They advocated the concept that the persistence of the echinoderm larva and its attainment of sexual maturity would have led to a stage known as the Neotenous larval phase. This particular larval form would have supplied all the raw materials for chordate evolution. Garstang (1894) also imagined that if the ciliated bands together

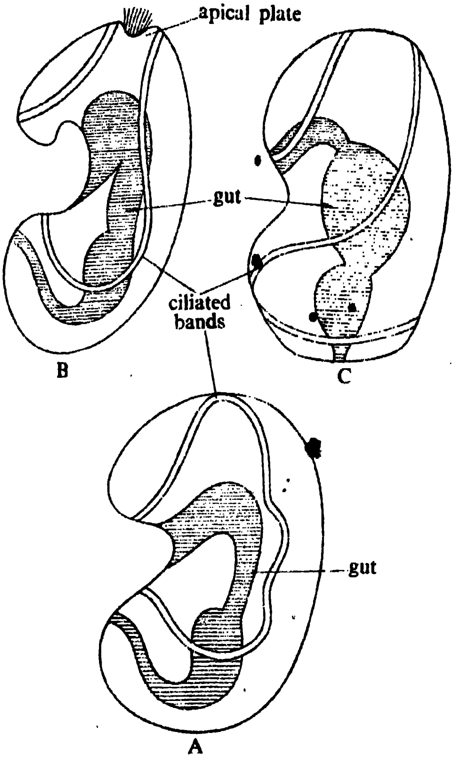


Fig. 3.3. Comparison between Tornaria larva with echinoderm larva. A. Tornaria larva. B. Bipinnaria larva. C. Auricularia larva.

with the underlying nervous tissue of Auricularia larva become accentuated to form ridges leaving a groove between them and if the lips of such grooves subsequently become fused to form a tube, a structure will be produced resembling the chordate nervous system. However, some more additional supports are necessary particularly from the palaeontological side. But the chances of finding conclusive fossil records of such soft bodied larvae are very remote.

Palaeontological evidences. The most primitive echinoderms recorded in the geological history are that of Cambrian and Ordovician Carpoid echinoderms. Torsten and Gislen assumed that the Carpoid echinoderms might have evolved from tornaria like creatures which have begun to settle down to lead a sedentary life. The water vascular system might have developed out of the ciliated grooves of the tornaria like forms. It has also been claimed that in the lower Silurian, one of the Carpoid echinoderms, had the calyx perforated by a series of 16 small apertures. These apertures are compared with the gill-slits of Branchiostoma. The carpoid echinoderms constitute a very divergent group and some forms also show a superficial similarity with some pteraspid ostracoderms.

Biochemical evidences. The phylogenetic relationship between the echinoderms and the chordates has been shown by biochemical studies also. Most of the invertebrates conduct energy transfer with arginine phosphate, but ophiuroids, cephalochordates, ascidians and vertebrates use creatine phosphate. The hemichordates and echinoids use both arginine phosphate as well as creatine phosphate. J. Needham (1932) has shown the presence of Phosphogen as the phosphorus-carrier in the echinoderms and chordates. Wilhelmi (1942) has shown the affinity between the two groups by serological tests. All these isolated biochemical studies put more weight to the concept of derivation of the chordates from the echinoderms.

Ancestry of Invertebrate Chordates

None of the theories except the echinoderm theory has received any attention, no matter how skillfully the theories have been presented. Neither annelids nor arthropods can be regarded as the ancestral form of the chordates. Efforts to make such derivations show the fallacy to derive one highly specialised group from another highly modified one. The recognition of real relationship between chordates and echinoderms has been the natural tendency at the present days, because the ancestral garment fits well upon the group. Attempts have been made to solve the problem from different angles:

1. Consideration of relationship in larval organisation.
2. Evidences deriving from the morphological studies.
3. Supports from the biochemical experimentations.
4. By comparing fossil echinoderms with the fossil chordates.

By setting aside the controversies on this issue, it is universally accepted that the dynamic larval forms of echinoderms hold the key of chordate ancestry. The recent inclination is to follow Garstang's view that the free-swimming auricularian larva by paedomorphosis have given origin to the chordates. Although no convincing evidence is ready at hand to explain the process of such transformation, it is assumed that the progenitors of the early chordates lie in some forms of echinoderm larvae.

Origin of the Vertebrates from Invertebrate Chordates

Claims have been made by many that vertebrates have been evolved directly from some invertebrate source. But the logical conclusion is that the Invertebrate chordates have been evolved from invertebrate (probably from the echinoderms) and the vertebrates originate from the Invertebrate chordates.

BRANCHIOSTOMA ANCESTRY

The theory of the origin of vertebrates from Branchiostoma appears to be convincing, because it fulfils the theoretical definition of a typical chordate organisation. Special emphasis has been put on the presence of notochord, dorsal tubular nerve cord and the pharyngeal gill-slits. For this reason it was believed that the Branchiostoma has channelised the line of vertebrate evolution. It has a fish-like appearance and gives a fairly typical picture of an early stage in the vertebrate evolution. Branchiostoma exhibits many structural similarities with the Ammocoetes larva of Lamprey. Both of them possess the following common characteristics: (1) 'V'-shaped myotomes. (2) Oral hood.

(3) Continuous dorsal fin. (4) Velum and velar tentacles. (5) Endostyle.

Due to the structural resemblances with the Ammocoetes larva it is suspected by many that the grade just above Branchiostoma in the evolution of vertebrate is well represented by Ammocoetes larva. But difficulties stand in assuming Branchiostoma as the true 'stem-form' in the evolution of vertebrates. Though it is undeniable that it has many archaic chordate characteristics, yet it may at best be regarded as the primitive chordate. A thorough survey of the anatomical organisation reveals the existence of many specialised as well as degenerated features. Such highly specialised and degenerated form cannot possibly react to the evolutionary dynamicity of the vertebrates. The structural organisation throws much light on the probable ancestral vertebrate form. Branchiostoma stands nearest to the true ancestral vertebrates but its sedentary habit offers the strongest obstruction in assuming the biological changes of the vertebrates from sessile animal like Branchiostoma.

BALANOGLOSSUS ANCESTRY

Balanoglossus is regarded as the ancestor of the vertebrates. The Tornaria larva shows marked resemblance with the echinoderm larvae. Wilder regarded the evolutionary succession of the hypothetical echinoderm ancestor into Balanoglossus and the Balanoglossus to the vertebrates. But difficulties lie in the fact that Balanoglossus does not fulfil the standard criterion of the chordate. The simpler organisation of Balanoglossus cannot be denied but its degeneration remains questionable. The so-called notochord (anterior extension of the dorsal wall of the pharynx) is a very doubtful structure. All the recent workers do not accept this structure as the notochord. The nervous system in Balanoglossus is more of invertebrate type than that of the chordate. So the only important chordate characteristic remains in the presence of pharyngeal gill-slits.

UROCHORDATE ANCESTRY

N. J. Berrill in his book "Origin of vertebrates" (1955) attempts to find a new line of approach on the problem of vertebrate evolution. Such a line of ancestry has never been proposed by any body. Urochordates have long been removed from the picture of the ancestry of vertebrates. But Berrill has tried to bring the urochordates to the forefront of vertebrate evolution. According to him, the question of degeneration is nothing anew in lower chordates. The sedentary habit of the urochordates shows close conformity with other sedentary Invertebrate chordates. Berrill wants to impress on the fact that the free swimming tadpole larva of urochordates has come from the sessile life of the vertebrates. This idea forces us to abandon the long accepted notion that from the free swimming larvae sessile condition in adult came into existence. Berrill thinks that the free swimming tadpole larva through developmental paedomorphosis (i.e., effectively exhausting the potencies of redifferentiation of cells through certain unknown factors) has avoided the sedentary condition and maintains a perennial free living habit. He added no importance to Branchiostoma as the direct ancestor of vertebrate and pretends that the immobile habit cannot possibly give rise to mobile vertebrates. Balanoglossus cannot hold the key of vertebrate line of descent. So Berrill is driven to the inevitable conclusion that the dynamic tadpole larva of urochordates is the actual source from which vertebrates have been evolved in space and time.

Berrill has put forward the following arguments to support his interpretation. According to him the tadpole larva in urochordate has been evolved within the group to fulfil certain specific ascidian needs and has never been inherited from others. In course of development some tadpole larvae become neotenous and ceased to metamorphose into adults. They started reproducing sexually as free-swimming organisms. This phenomenon has taken place in the oceanic surface water. During the earlier part of the pelagic evolutionary phase some members used to exploit the river mouth. The effective locomotory power has enabled the tadpole larvae to make an excursion into the far extent in the river system. At first, such excursion into the river system was intended solely for feeding and they used to return to ocean for breeding. Branchiostoma, as we see today, is one of such relics of such transitional phase which rediscovered some advantages of oceanic life and become readapted to it. Within the river system, such tadpole larvae directly evolved into relatively simple unarmed ostracoderms. Such ostracodems represent the vertebrate prototype which has given origin to the specialised ostracoderms and subsequently to the true fishes.

The probable line of evolution of Vertebrates is shown in Figure 3.4.

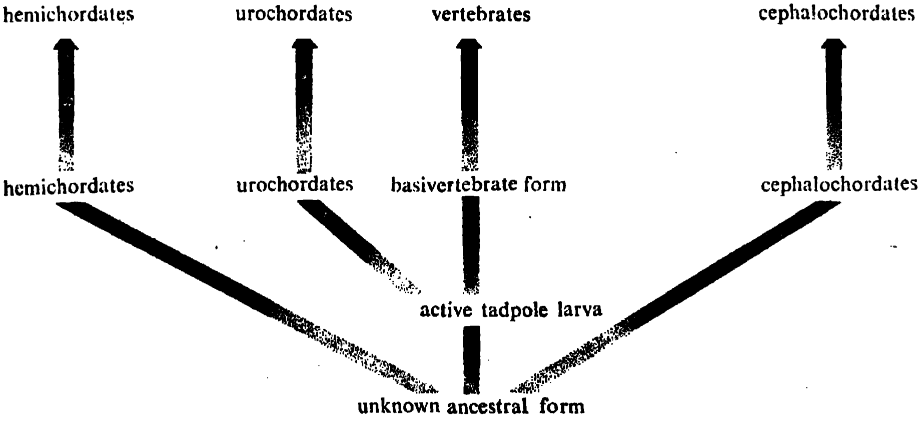


Fig. 3.4. Showing the probable line of vertebrate origin.

Time of origin

The chordates constitute very ancient forms and the tangible fragmentary remains of the invertebrate chordates have been recorded in the Cambrian strata and that of ostracoderms in the middle Ordovician time. But the relics discovered in the strata, are of those creatures who had already travelled a long evolutionary way. It can safely be said that the time of origin was not later than the beginning of the Ordovician, if not long before.

Place of origin

The place of origin is not clear. The actual place of origin of the early chordates is probably the sea. It is accepted that some echinoderm larvae in course of development have given origin to some Invertebrate chordates. Both the echinoderm larvae and the Invertebrate chordates are all marine. From this point it can be suggested that the early chordates evolved in sea. But the place of origin of vertebrates is not definitely known. There is no direct evidence about the exact site of origin. With all probabilities, the place of origin lies in the river system very near to the sea. This concept of fresh water origin of the vertebrates is sponsored by recent workers of this line.

SUMMARY

1. The phylum Chordata include two major groups—the invertebrate chordates and the vertebrates. The vertebrates possess a vertebral column and a cranium, which are lacking in invertebrate chordates.

2. Although based on the same fundamental plan, the invertebrate chordates and vertebrates exhibit a number of contrasting characters.

3. The origin of the vertebrates in space and time is a very complicated problem.

4. Many theories exist on the ancestry of the vertebrates. All the theories can be moulded into one idea that the invertebrate chordates originating from invertebrate have channelised the vertebrate evolution.

5. Some forms of echinoderm larvae are accepted to hold the ancestry of the invertebrate chordates. There are many supporting evidences on this point.

6. The free-swimming ascidian tadpole, after emerging from unknown echinoderm ancestor, has evolved into the vertebrates.

CHAPTER 4

Phylum Chordata—Jawless vertebrates

The extinct ostracoderms and their present descendants, the cyclostomes constitute a special group of jawless vertebrates (Fig. 4.1). They are undoubtedly the most ancient of all the vertebrate forms and furnish an interesting instance of experimentation on feeding prior to the emergence of biting jaws. As a consequence of such special mode of feeding the structural organisation of this group becomes very much modified. The present chapter deals with the jawless vertebrates (agnathans) with an idea to get an insight of the biology of early vertebrates.

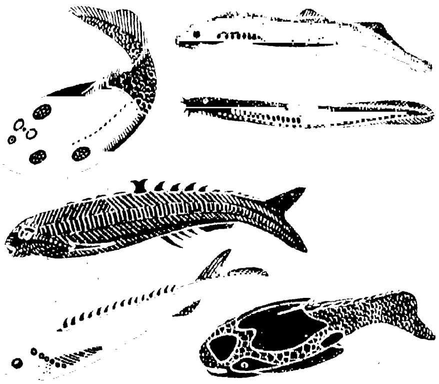


Fig. 4.1. A few agnathans. Note the absence of paired fins and biting jaws.

CLASS OSTRACODERMI

The class Ostracodermi is represented by the fossil vertebrates of the Ordovician rocks. Although the fossils are mostly observed in the seas, there are ample reasons to believe that their progenitors were fresh-water forms living near the estuaries.

IMPORTANT FEATURES

The bony plates and the scales of the ostracoderms are well-preserved. They had fish-like bodies with heavy head armour. The literal meaning of the group is 'shelled-skinned' animals which signifies the head armour. Some of the forms had one pair of fins behind the head. The paired eyes were situated on the top of the head. The gills-slits were round and all have similar gill-pouches. The endoskeleton was moderately ossified. Two semicircular canals were mostly present in the ear.

OUTLINE CLASSIFICATION

The class Ostracodermi is classified into four orders. The orders are as follows: (1) *Euphanerida*, (2) *Pteraspidomorphi*, (3) *Cephalaspidomorphi* and (4) *Anapsida*.

EXAMPLE OF OSTRACODERMI—CEPHALASPIS

Cephalaspis is the best known genus of the class Ostracodermi that lived during the Silurian and Devonian times.

Habit and habitat

Cephalaspis is a bottom dweller and inhabits the shallow water. It excavates through mud and sucks in minute food particles that enter through the mouth.

External structures

Cephalaspis has a small fish-like body (Fig. 4.2). The body is divided into *head*, *trunk* and *tail*. The head is dorsoventrally flattened and remains covered by a stout bony *carapace* (or *head shield* or *cephalic shield*). The trunk is protected by bony plates which are oriented vertically. A median dorsal fin is present in the posterior part of the trunk. The tail is heterocercal and is provided with small scales. The head shield is formed of a single bony piece which is projected posteriorly in the forms of two *lateral horns* or *projections*, one on each side of the head. Attached to these lateral plates there are two lobed *pectoral fins*, one on each side of these plates. These fins are covered over by scales. A pair of closely-placed *eyes* is present on the top of the head. A single median nostril is located immediately in front of the eyes. A small pineal opening is placed in between the eyes. Two prominent dorsolateral depressions called the lateral '*sensory fields*' are recognised. These are believed to be the electric organs by many workers. But such an idea becomes difficult to accept when comparison is made with that of *Torpedo*, a living electric fish. In Torpedo, the electric organs are composed of specialised muscles innervated by the

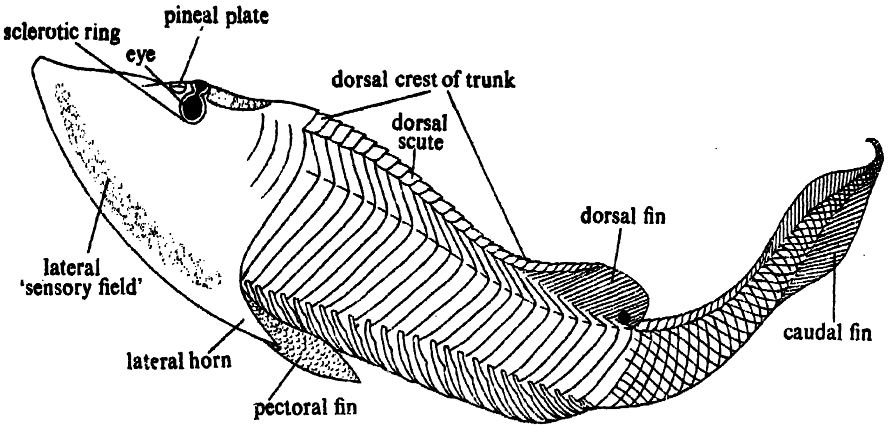


Fig. 4.2. External features of a cephalaspid ostracoderm, *Cephalaspis*.

branches from the seventh and tenth cranial nerves. But in Cephalaspis, five pairs of nerves from the acustico-lateralis region of the brain run to the depressions. The lodgement of the muscles in depressions outside the cephalic shield remains still difficult to interprete.

The ventral surface of the head is protected by a few small fine plates. The mouth is a circular opening situated at the anterior end of the ventral surface. The mouth is devoid of biting jaws. The gill-slits are roundish openings. The gill-slits are arranged in two semicircles on either side of the mouth. There are about ten pairs of gill-slits. The mouth and the gill region are collectively called the *oro-branchial area* which is protected by a system of minute bony plates.

Internal structures

Internal anatomical construction of Cephalaspis is incompletely known. It is presumed that the internal skeleton was mostly cartilaginous, as a consequence, fossilisation was mostly incomplete. It possesses a lowly formed brain with ten pairs of cranial nerves. Five pairs of broad nerves emerging from the acustico-lateralis region of the brain form a well-formed system of nerves running to the lateral 'sensory fields'.

CLASSIFICATION

CLASSIFICATION IN OUTLINE

Order *Euphanerida*, e.g., *Jamoytius*
Order *Pteraspidomorphi*, e.g., *Pteraspis*, *Thelodus*, *Lanarkia*. *Drepanaspis* and *Coelolepis*.
Order *Cephalaspidomorphi*, e.g., *Cephalaspis*, *Hemicyclaspis*, *Atcleaspis*, *Benneviaspis* and *Thyestes*.
Order *Anapsida*, e.g., *Birkenia*, *Pterolepis*, *Rhyncholepis* and *Lasanius*.

CLASSIFICATION WITH CHARACTERS

Order *Euphanerida*

This order is represented by a single genus *Jamoytius*. Stensio and Ritche (1960) included Jamoytius under Anapsida. This fossil was discovered in the Silurian strata of England. It measures about 18 cm in length. Jamoytius has a very primitive body construction. The body is unarmoured. The idea about the fossil came from the impression left in rock. The lateral fin folds and the myotomal muscles are exactly like that of *Branchiostoma*. Jamoytius is regarded as the most archaic form in the phylogenetic history of the vertebrates. Newth regarded Jamoytius as the Ammocoetes larva of an ostracoderm.

Order *Pteraspidomorphi*

The members of this order are the heavily armoured ostracoderms of the middle Ordovician to Devonian periods. The fins are absent. The head is flattened and is protected by a bony cephalic shield (Fig. 4.3). The tail is laterally compressed and is covered by small scales. The tail fin is of heterocercal type. The mouth is a slit-like aperture. The eyes are widely separated. The nostrils, when present, are paired. The gill-pouches unite to form two gill-slits, situated one on each side behind the cephalic shield. The anterior portion of the snout is prolonged into a long rostrum. A backwardly directed dorsal spine projects upwards from the posterior part of the cephalic shield. The trunk is covered over by rectangular scales. Lateral line is distinct. The examples are: *Pteraspis*, *Lanarkia*, *Thelodus*, *Coelolepis* and *Drepanaspis*.

Order *Cephalaspidomorphi*

These ostracoderms have a single nasal aperture situated far back on the head The eyes are closely placed on the dorsal side of the carapace. The head is expanded, dorsoventrally flattened and is covered by a thick continuous cephalic shield (carapace) which is prolonged laterally into two lateral horns. The surface of the carapace is ornamented with spines and tubercles. The trunk is covered by elongated vertical scales. Well-formed dorsal and pectoral fins are present. The tail is heterocercal. The typical representatives are: *Cephalaspis*, *Hemicyclaspis*, *Thyestes*, *Didymaspis*, *Benneviaspis*, *Kiaeraspis* and many others.

Order *Anapsida*

This order includes the small fish-like ostracoderms. The fossils are recorded from Silurian to Devonian periods. The head is protected by small scales. The arrangement of the scales is complicated. In the trunk the scales are oriented in longitudinal rows. The tail is hypocercal, i.e., downwardly turned.

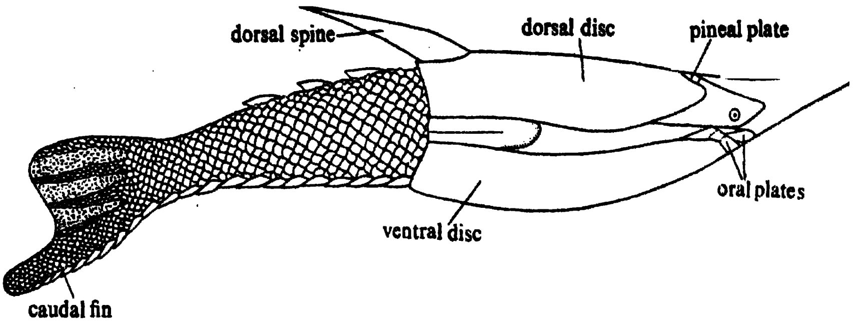


Fig. 4.3. External features of a pteraspid ostracoderm, *Pteraspis*.

The mouth is terminal in position. The eyes are laterally placed with a median nostril. The paired appendages are represented by a pair of pectoral spines. A series of spines is present in the middorsal line of the trunk. An anal spine may be present. Gill-slits are present in a slanting fashion in front of the pectoral spines. Examples: *Birkenia*, *Lasanius*, *Pterolepis*, *Rhyncholepis* and *Pharyngolepis*.

BIOLOGICAL STATUS OF OSTRACODERMS

The ostracoderms are the most primitive vertebrates recorded in the geological history. Majority of the forms lived from the upper Silurian to Devonian times. They have possibly evolved from unarmoured ancestral forms like *Jamyotius* and become diverged to various modes of life. Now the question stands whether the ostracoderms should be placed in the direct line of vertebrate descent. It is certain that the group shows many structural similarities with the cyclostomes and fishes. In the opinions of many, the cyclostomes (the most primitive surviving vertebrates) are the degenerated descendants of some forms of ostracoderms. There are strong evidences in favour of this view. But the relationship of the ostracoderms with the gnathostomes is still obscure. The jawed vertebrates evolved simultaneously with the ostracoderms during the Devonian period and no fossil link is so far discovered in the line of transformation. The anapsid ostracoderms are small-headed fish-like forms and exhibit many features of the earliest fishes. During Devonian period the ostracoderms showed high degree of specialisation and the fishes must have emerged from the primitive forms at some earlier geological period. In spite of all these difficulties, it is apparent that the anapsid ostracoderms are not very far from the line of descent of the jawed vertebrates.

Class Cyclostomata (Marsipobranchii)

This class includes only the living agnathous animals of lower grade of organisation amongst the existing craniates. They are characterised by having many peculiar characteristics.

IMPORTANT FEATURES

The class Cyclostomata comprises of the most primitive living vertebrates represented by the lampreys and hagfishes. The cyclostomes, in general, show the curious admixture of primitive, specialised and degenerated characters. They have the following common salient features: (1) The mouth is circular in outline from which the name Cyclostomata (*Cyclo*=round; *stoma*=mouth) has been derived. (2) The mouth is suctorial. Horny epidermal teeth are present in the interior of the mouth and on "tongue". (3) The skin is naked and glandular. (4) The median fin is present which is not supported by true fin-rays. (5) The skull is largely or wholly roofed by membrane. (6) The labial cartilage is extensively developed. (7) The vertebral column consists of a persistent notochord with a fibrous neural tube in which rudimentary neural arches may develop. (8) The notochord is continuous and enveloped by two sheaths. (9) The alimentary canal is straight and cloaca is absent. (10) The respiratory organs consist of the gill-pouches. The pouch-like gills have given another name, MARSIPOBRANCHII to the class. (11) The conus arteriosus and the renal portal system are absent. (12) The olfactory lobes are large and are either hollow or solid. (13) The cerebellum is very small. (14) The nerves are non-medullated. (15) A single median olfactory organ is present which opens into a large persistent pituitary sac. (16) The ninth and the tenth cranial nerves are not included in the cranium. (17) The gonad is unpaired and is devoid of gonoduct. The genital products pass out through the genital pores.

OUTLINE CLASSIFICATION

The class Cyclostomata is divided into two subclasses—(1) PETROMYZONTIA examplified by the lampreys and (2) MYXINOIDEA represented by the hagfishes.

EXAMPLE OF CYCLOSTOMATA—LAMPREY

The most common and widely distributed cyclostomes are the lampreys or 'Lamper eels' belonging to the family Petromyzontidae. Their characteristics, habit and habitat present an idea about the biology of the earliest vertebrates. Two distinct phases are recognised in the life-history of the lampreys: (1) ADULT STAGE. In this stage, lampreys are marine and possess suctorial mouth. They are carnivores and feed on other fishes. (2) LARVAL STAGE. The larval stage is represented by Ammocoetes larva which inhabits the fresh water. It remains buried in the mud and devours micro-organisms. This larva resemblances closely the adult Branchiostoma.

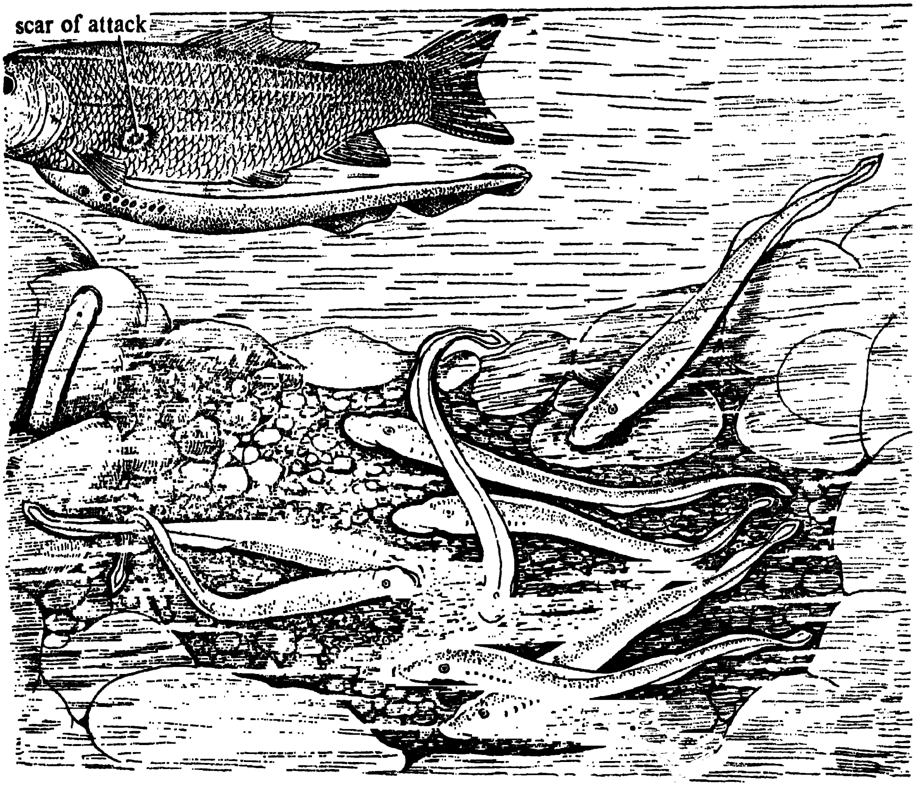


Fig. 4.4. A group of *Petromyzon* in their usual habitat. Note that the animals remain attached to the body of fish or stones by their suctorial buccal funnels. Nest building is characteristic of the *Petromyzon*. A small depression is produced at the center by arranging larger stones on all the sides.

Habit and habitat

Lampreys have almost a world-wide distribution. All of them are predators and live on fishes, turtles and many other aquatic animals. They are often referred as quasi-parasitic which is not true in biological sense. Although they have the power of swift swimming, they usually remain attached to other fishes or stones by the help of suctorial buccal funnel which acts as the vacuum cup. While attached to the fishes, they rasp the flesh by the horny teeth on the buccal funnel and 'tongue' apparatus.

Lampreys usually live in sea and migrate to the river for the purpose of spawning. After spawning they usually die. In the river system the lampreys do not eat anything, but live on the accumulated subcutaneous fat that provides the nourishment. They migrate to the river usually in autumn while the sexual maturity is attained in winter. But the breeding occurs in spring. A fresh water lamprey, *Petromyzon marinus unicolor* migrates a few miles up streams for the purpose of spawning. The brook lampreys (represented by the genus *Lampetra*) have the peculiar habit of nest-building at the bottom of the river where the eggs are laid. They select the bottom where both stones and sands are present. By the action of the suctorial mouth, they arrange the stones in such a fashion that a small depression is produced at the centre (Fig. 4.4).

External structures

The adult lamprey has an eel-like cylindrical body (Fig. 4.5A). The upper side of the body is usually dark and the lower surface is white. The surface of the body is smooth and slimy. The scales are absent. The body is divided into three regions, the *head*, *trunk* and *tail*. The head and trunk are cylindrical and the tail is more or less laterally flattened. Paired fins are absent. There is median *dorsal fin* which is divided into two unequal parts by a notch. A caudal fin is present which is continuous with the posterior part of the dorsal fin. In *Lampetra planeri* the female possesses an anal fin. This fin is reduced to a *copulatory papilla* in male. A small opening called the *anus* is present in the ventral side of the junction of the trunk and tail. The fins are supported by cartilaginous fin-rays. These rays are fused at their basal ends with the membranous covering that surrounds the notochord and nerve cord.

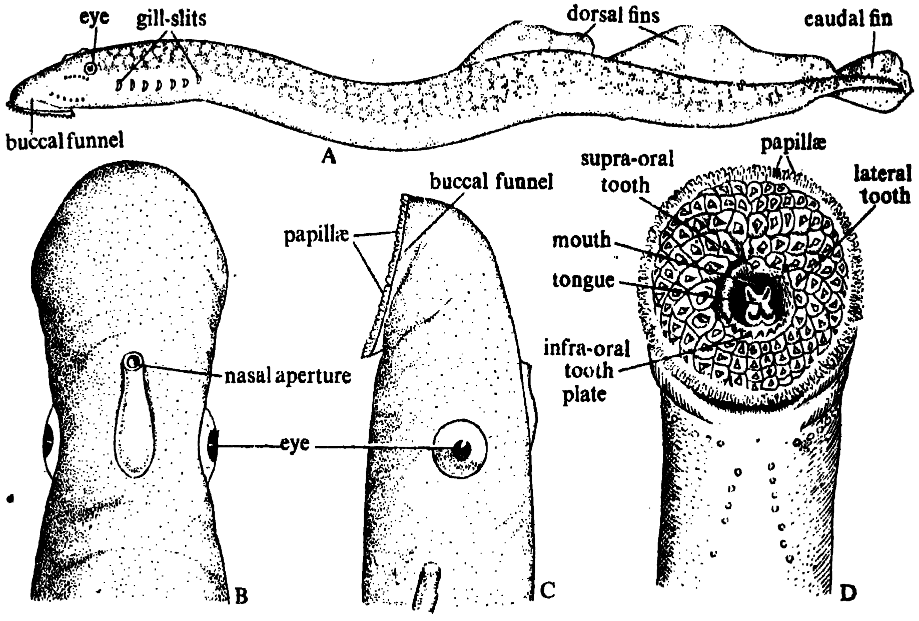


Fig. 4.5. External structures of *Petromyzon*. A. An entire animal (lateral view). B. Dorsal view of head showing the position of the nostril. C. Lateral view of the head. D. Ventral view of the head showing the details of buccal funnel and the position of mouth and 'tongue' (after various sources).

The head region is characterised by the development of a special cup-like structure called the *buccal funnel*. This funnel is actually a downwardly directed depression. The rims of the buccal funnel is beset with papillae. Numerous small horny teeth are present inside the cavity. The mouth is a circular opening situated at the bottom of the buccal funnel. A special '*tongue*' apparatus is placed just below the mouth (Fig. 4.5D). The tongue is a prominent structure and bears horny teeth. On the dorsal side of the head there is a single median *nostril* (Fig. 4.5B). Just behind the nasal opening, there is a yellow spot indicating the position of internal *pineal eye*. The paired eyes are well-developed (Fig. 4.5C). Seven pairs of round *gill-openings* are present on the posterolateral sides of the head and the anterior part of the trunk.

Body wall and musculature

The skin is soft and consists of many layers of cells. The *epidermis* is composed mostly of unicellular gland cells that produce slimy secretion. The *dermis* is composed of bundles of collagenous and elastic fibres. These fibres are arranged in a circular fashion. Between the dermis and body wall musculature, there lies a subcutaneous layer containing pigment cells, blood vessels and fatty tissue. The pigment cells or chromatophores have the power of migration and also present in the dermis.

The trunk musculature is well-developed. The muscles are arranged in *myomeres*, i.e., there are series of *myotomes* separated by *myocommas*. The myotomes are W-shaped muscle blocks and the muscle-fibres composing the myotomes run longtudinally. The muscle-fibres are striated. The myotomes are divided into dorsal and ventral parts by horizontal septum.

Locomotion

Lampreys swim by the activity of the myotomal longitudinal muscle-fibres. Swimming is effected by producing waves of curvature down the body, alternately on each side. In lampreys, the waves are very short in comparison to the body length, as a consequence progression is not so rapid. The mechanism of swimming is similar to that of Branchiostoma already described in Chapter–2. Expulsion of water through the gill-openings like jets also help in progression.

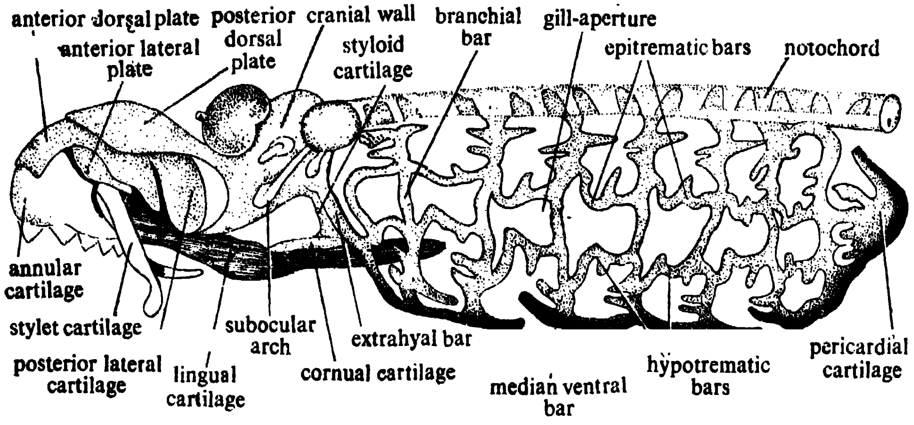

anterior dorsal plate
anterior lateral plate
dorsal plate
posterior cranial wall
styloid cartilage
branchial bar
gill-aperture
epitrematic bars
notochord
annular cartilage
stylet cartilage
posterior lateral cartilage
lingual cartilage
subocular arch
extrahyal bar
cornual cartilage
median ventral bar
hypotrematic bars
pericardial cartilage

Fig. 4.6. Structure of the skull and branchial basket of an adult *Petromyzon* (after Parker and Haswell).

Skeletal structures

The axial skeleton consists of a lowly developed SKULL, persistent NOTOCHORD and collection of cartilages. The notochord is composed of large vacuolated *notochordal cells* and remains enveloped by a thick fibrous *notochordal sheath*. This is further surrounded by another connective tissue layer which covers the spinal cord and remains connected with the myocommas. Within the connective tissue layer there are scattered thickening of cartilaginous elements. These are compared with the vertebrae. The cartilage consists of large cells embedded in a matrix of *chondrin*. Many slender cartilaginous rods extend dorsally and ventrally to support the median fin.

The SKULL is very peculiar and primitively built. Its floor is composed of a *basal plate* which is composed of paired *parachordals* and *trabeculae*. Attached with the basal plate there are pieces which form an incomplete cartilaginous box enclosing the brain and the special sense organs. In front of the cranium, a large aperture is left due to the non-united posterior parts of the trabeculae. This aperture is called the *basicranial fontanelle* and through this aperture the pituitary pouch passes. The side walls of the cranium is strong but the roof is exclusively composed of tough membranous fibrocartilage excepting a narrow transverse bar. Two compact *auditary capsules* are united with the posterior end of the basal plate. The *olfactory capsule* is an imperfectly paired plate which supports the posterior wall of the olfactory sac. This capsule is united with the cranium by fibrous tissue. On each side of the basal plate, there lies the *subocular arch* to support the eye. A slender *styloid process* hangs from the subocular plate. Each styloid process is connected with a small *cornual cartilage*. The cranium is attached with the skeleton that supports the gills and buccal funnel (Fig. 4.6).

The BRANCHIAL BASKET is composed of nine irregular vertical cartilaginous *branchial bars* or *rods* on each side. The first vertical branchial rod is situated just posterior to the styloid process, the second is in front of the first gill-slit and the rest are just posterior to the remaining gill-slits. The vertical bars are connected by the longitudinal bars. The posterior part of the branchial basket is extended to form a cup-like *pericardial cartilage* to accommodate the heart. The branchial skeleton is compared by many workers with the visceral skeleton of higher vertebrates. But such an idea becomes difficult to establish because in lampreys the basket is situated outside the muscles and nerves. But in case of fishes these are present in the pharyngeal wall.

The buccal funnel is supported by a ring-like *annular cartilage*. An elongated *lingual cartilage* supports the 'tongue'. cartilage and the anterior end is prolonged as a *lingual tendon* to attach with the tongue. The vacuum cup is produced inside the oral cavity by the pulling of the tongue backwards by the contraction of the cardioapicalis muscle. The release of the sucker is effected by the contraction of an *annular muscle* running along the margin of the buccal funnel.

The mouth leads into a spacious *buccal cavity* which is communicated behind with two passages. The dorsal passage is called the *gullet* or *oesophagus* and the ventral one is the *respiratory tube* (Fig. 4.7). The respiratory tube is closed behind and leads into seven *branchial-* or *gill-pouches*. The opening of the respiratory tube is guarded by a *velum* with *velar tentacles*. The velar apparatus keeps the digestive part completely separated from the respiratory tube when the animal feeds. The oesophagus leads directly into a straight *intestine* by a valvular aperture. True *stomach* is absent in lampreys. The intestine passes to the *anus*. In the lumen of the intestine, a typhlosole is present which follows a spiral course and thus gets the name *spiral valve*.

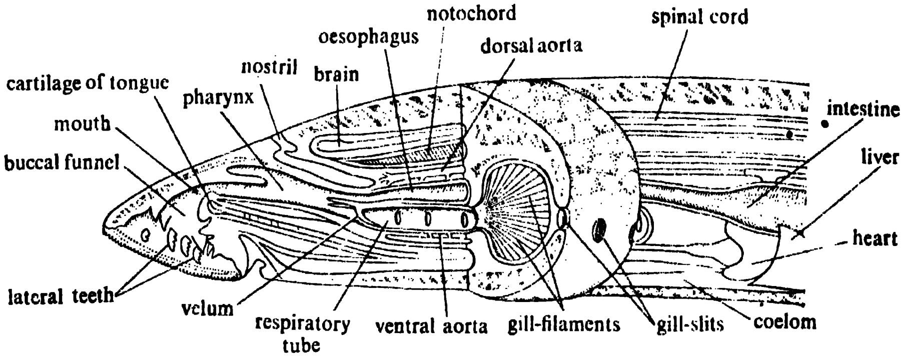


Fig. 4.7. Longitudinal sectional view of the anterior portion of *Petromyzon* to show the relative position of the internal structures. A portion of the body is kept intact to show the position of a gill-slit (after Storer and Usinger).

Digestive system

The mouth is situated immediately above the 'tongue' inside the buccal funnel. The buccal funnel is a specialised cup-like depression which acts as a sucker. Numerous teeth are present in the buccal funnel. These teeth are very peculiar and develop as horny epidermal thickenings having cartilaginous support. The teeth that are borne on the tongue are elongated and sharply pointed. The teeth are capable of being replaced, if lost. Special set of muscles operate the buccal funnel and the tongue apparatus. Lampreys can attach with the body of other fishes by producing a vacuum cup inside the buccal funnel. This is caused by a large *cardioapicalis muscle*. The muscle is connected posteriorly with the pericardial

The digestive glands are well-developed in lampreys. A pair of pigmented sacciform structures, present inside the hypobranchial muscles, is regarded as '*salivary glands*'. But the nature of secretion of these glands is still unknown. Each gland has a folded wall and the secretion is poured through a duct which opens below the tongue. The secretion contains anticoagulant which prevents the coagulation of the blood during feeding. The LIVER is a voluminous bilobed structure. Gall bladder is present in the larval stage, but it is absent in the adult.

There is no definite PANCREAS, but patches of cells in the anterior part of the intestine are compared with the *pancreatic acini* of the higher vertebrates. The cells secrete pancreatic enzymes which are largely tryptic in nature. The endocrine function of these structures has also been experimentally established. If the tissue is destructed, a marked rise of blood sugar level is recorded. The cells become extremely vacuolated, if glucose is injected into the body. From the above facts, it is amply clear that these cells do participate in carbohydrate metabolism of the body.

The actual mode of feeding in lampreys is not known. While attached with the body of fishes, they eat the flesh by rasping with the tongue apparatus. The intestine of a freshly detached lamprey is found to be filled with blood which also indicates their sanguinivorous habits.

Respiratory system

The respiratory system consists of seven pair of *gill-* or *branchial-pouches* or *branchial sacs*. The gill-pouches open directly into the respiratory tube and have no direct connection with the enteric canal. Each gill-pouch has an appearance of a biconvex lens. The inner wall is folded to form numerous *gill-lamellae* and the outer wall is highly muscular (See Fig. 4.7). The gill-pouches are separated from each other by *interbranchial septa*. Each gill-pouch in lampreys opens independently to the exterior. Seven pair of external *gill-pores* are visible on the two sides of the body.

The mechanism of drawing in and expelling out of water through the gill-pouches is very peculiar in lampreys. This is because of their specialised mode of attachment. The water enters into the respiratory tube through the gill-pouches and passes out through the same route. The branchial skeleton is elastic. The branchial basket is compressed by the contraction of the muscles to throw the water like jets through the gill-openings, while during inspiration the branchial basket expands. The gaseous exchange occurs inside the gill-pouches.

Circulatory system

The circulatory system is well-developed. There are no definite lymphatic channels in lampreys. The HEART is an S-shaped structure situated behind the gills. It develops in the larva as a straight tube which becomes elongated in a limited space to become S-shaped. It is composed of three chambers—one *sinus venosus*, one *auricle* and one *ventricle* (Fig. 4.8). The heart is enclosed by a pericardium which is supported by a cartilaginous plate. The sinus venosus is a thin-walled chamber and leads into a thin-walled auricle lying above the sinus venosus. The auricle opens into the thick-walled ventricle. The conus arteriosus is absent.

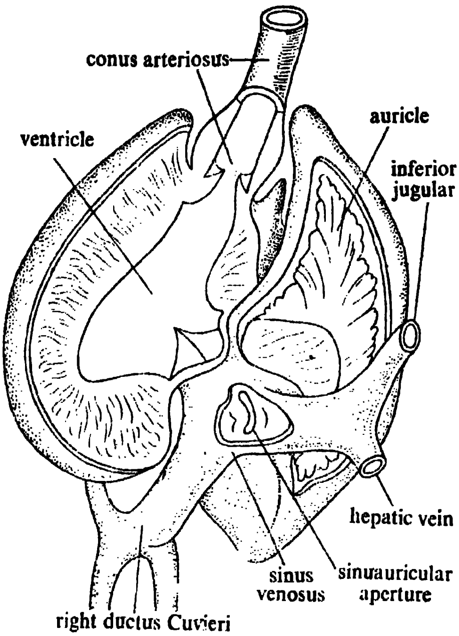


Fig. 4.8. Diagrammatic longitudinal section of the heart of *Petromyzon*. The chambers are exposed showing the internal details (after Jollie).

The BLOOD of lamprey is red in colour due to haemoglobin contained inside the red blood corpuscles. These corpuscles are nucleated and circular in outline. The white corpuscles are closely similar to the lymphocytes and polymorphs of higher vertebrates. The blood forming tissue is present in the kidneys and the spinal cord.

Arterial system

From the ventricle a large *ventral aorta* runs anteriorly between the gill-pouches. The base of the ventral aorta slightly dilates to form a *bulbus arteriosus*. The ventral aorta gives eight *afferent branchial arteries* to the gill-pouches. The afferent branchial arteries break up into capillaries in the gills. From the gills, the blood is collected by eight *efferent branchial arteries* (Fig. 4.9). Each of the afferent and efferent branchial arteries supplies to the posterior hemibranch of a gill-pouch and the anterior hemibranch of the next. The efferent branchial arteries open into the *paired dorsal aortae.* These paired aortae run backward and then unite to form a single *median dorsal aorta* which in turn gives series of *segmental arteries* to the myotomes. Special arteries from the unpaired dorsal aorta supply blood to the gut, kidneys and gonads. Most of the arteries except the efferent branchial and renal arteries are provided with valves at the point of origin. The presence of the valves is significant, because these valves help in reducing the pressure of the blood in most of the arteries.

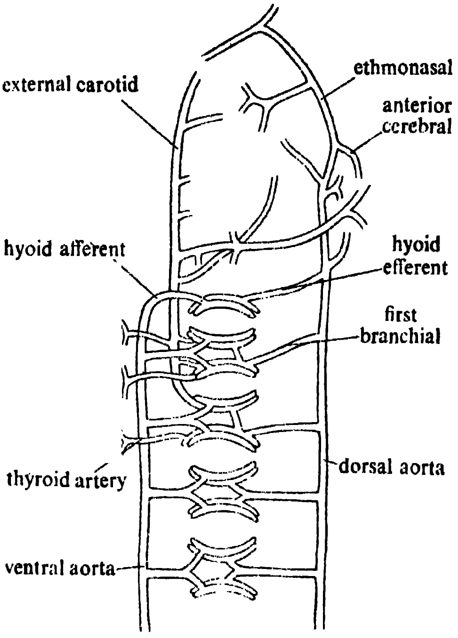


Fig. 4.9. Schematic lateral view of the anterior part of the arterial arches of *Petromyzon* (after Jollie).

The blood flows anteriorly through the ventral aorta and backwardly through the paired and unpaired dorsal aortae.

Venous system

The venous system of lampreys consists of true *veins* and a complicated network of *venous sinuses*. The blood from the tail region is carried by a large *caudal vein.* This vein divides anteriorly into two *posterior cardinal veins* just at the point of the entrance into the abdominal cavity. The cardinals collect blood from the kidneys, gonads and myotomes and ultimately open to the heart by a single *ductus Cuvieri* on the right hand side. The left ductus Cuvieri is absent in adult, although both are evident in the larval stage. The blood from the anterior region of the body is conveyed to the heart by a pair of *anterior cardinal veins.* Besides these anterior cardinals, a large *median inferior jugular vein* drains blood from the musculature of the buccal funnel and gill-pouches. There is no renal portal vein, but a *hepatic portal vein* draining blood from the gut enters into the liver through a *contractile portal heart.* A very simple portal system is present which connects the hypothalamus with the pituitary. From the liver, blood is carried to the heart by *hepatic veins.* Besides the veins, there are special network of venous sinuses specially in the head region. The *branchial sinuses* constitute the most important of the sinuses and consist of three longitudinal channels. These are: (1) *Ventral branchial sinus or ventral jugular sinus,* (2) *Inferior branchial sinus* situated below the gill-pouches and (3) *Superior branchial sinus* lying over the gill-pouches. All these branchial sinuses are interconnected through the gill-bars.

Nervous system

The nervous system of lamprey is quite well-developed and the description of this system will represent an introductory account of the typical vertebrate nervous system.

Brain

The neural tube becomes modified anteriorly into a complicated BRAIN and the posterior part transforms into the SPINAL CORD. The brain is divided into three primary parts, *forebrain* or *prosencephalon, midbrain* or *mesencephalon* and *hindbrain* or *rhombencephalon.* The prosencephalon is mainly connected with the sense of smell, the mesencephalon with the sight and the rhombencephalon with the acoustic-lateral and taste-bud systems. The prosencephalon is subdivided into *telencephalon* and *diencephalon.* The telencephalon consists of *cerebral hemispheres* (*cerebrum*) and *olfactory lobes.* The diencephalon (or between-brain) remains posterior to the cerebral hemispheres. The mesencephalon forms the *optic lobes.* The rhombencephalon is divided into two parts, an anterior *metencephalon* transforming into a *cerebellum* and a posterior *myelencephalon* or *medulla oblongata.* The brain is covered externally by a vascular membrane called the *choroid plexus* or *tela choroidea* (Fig. 4.10).

The prosencephalon consists of a pair of small cerebral hemispheres and a pair of *olfactory bulbs*. The olfactory bulbs give paired *olfactory nerves* to the *nasal capsule*. The hypothalamus is well-developed. It bears inconspicuous inferior lobes and indistinct '*saccus vasculosus*'. The supraoptic nucleus of the hypothalamus sends nerves to the par nervosa of the anterior pituitary lobe. On the ventral side of the diencephalon lies the simple crossing of optic nerves which do not form chiasma. The *velum transversum*, that demarcates the anterior end of the diencephalon of the vertebrate brain is absent. The midbrain is represented by two *optic lobes*. Between the optic lobes lies a membranous choroid plexus which is fused with plexus lying over the fourth ventricle, i.e., the cavity of the myelencephalon. So the choroid plexus thus extends into the ventricles at three places. The cerebellum is a small trans-

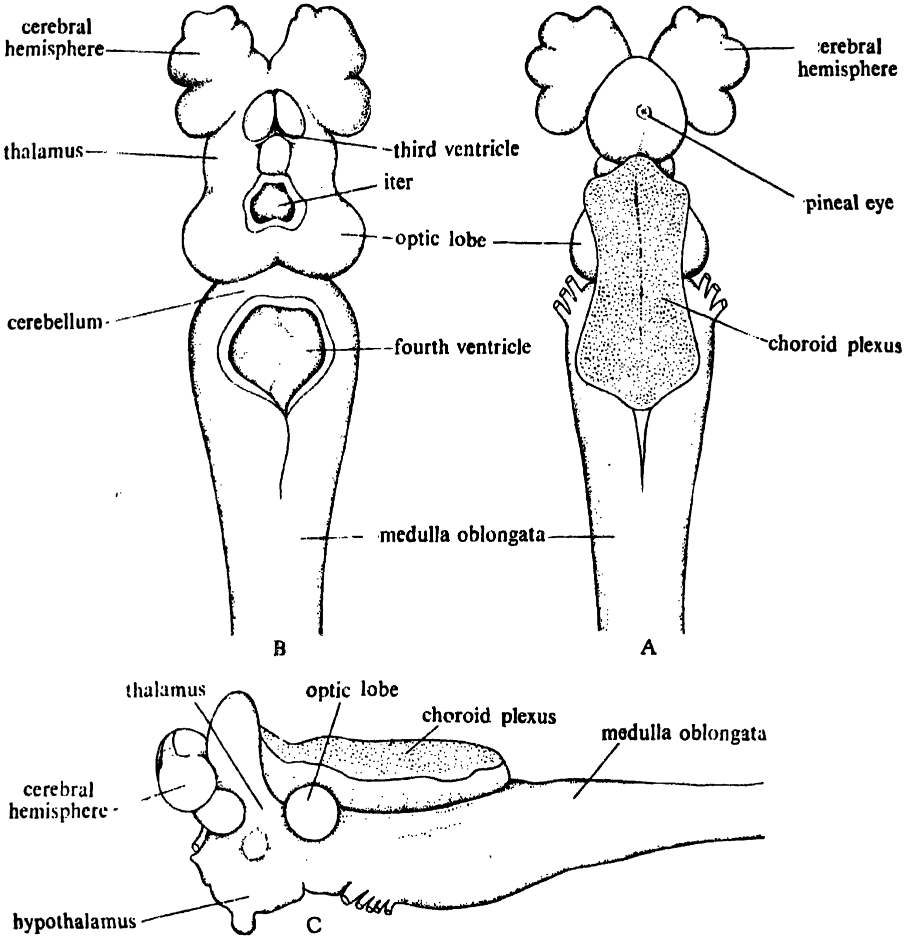

cerebral hemisphere
thalamus
third ventricle
iter
optic lobe
cerebellum
fourth ventricle
medulla oblongata
B
:erebral hemisphere
pineal eye
choroid plexus
A
thalamus
optic lobe
choroid plexus
medulla oblongata
cerebral hemisphere
hypothalamus
C

Fig. 4.10. Brain of *Petromyzon*. A. Dorsal view having the choroid plexus intact. B. Dorsal view after removing the choroid plexus. C. Lateral view (after Young).

The olfactory bulbs contain small *ventricles*. The cavities of the cerebral hemispheres are called the *lateral* or *first* and *second ventricles*. The lateral ventricles are in communication with the *third ventricle* or *diacoel* (cavity inside the diencephalon) through the *foramen of Munro*. The diencephalon has a membranous roof which protudes outwards as a conspicuous *saccus dorsalis*. The lateral walls are known as the *thalamus* and the ventral part is called the *hypothalamus*.

verse lobe anterior to the medulla oblongata which is the largest and well-developed part of the brain in lampreys. The third and the fourth ventricles are communicated through a duct passing through the midbrain. This duct is called the *iter* or *aqueduct* of *Sylvius*.

Spinal cord

The spinal cord is a dorsoventrally flattened band-like structure. The spinal cord in lampreys is peculiar of having no blood-vessels within it. The nerve cell bodies are localised towards the centre and the periphery is composed of network of nerve fibres.

Cranial nerves

There are ten pairs of CRANIAL NERVES in lampreys. All these nerves emerge out from the mesencephalon and rhombencephalon except the olfactory and optic nerves. The general arrangement of the cranial nerves are almost similar to that of the gnathostomes (discussed in details in Chapters 5 and 6) with slight variation. Only the contrasting features of the cranial nerves in lampreys are mentioned here. The *olfactory nerves* are composed of many nerve fibres. The *optic nerves*, as already mentioned, form simple crossing without having complicated chiasma formation. The *oculomotor* nerves lack decussation. The existence of the sixth cranial nerve in lamprey is questioned by many workers, because the said nerve emerges out along with the *trigeminal* (fifth) cranial nerve. The trigeminal and the *facial* (seventh) nerves are intimately associated and their branches to the lateral-line sensory system are difficult to identify. The roots of the seventh and eighth cranial nerves are closely placed. The branching of the *glossopharyngeal* and *vagus* nerves is similar to that of fishes. The origin of vagus is characteristic in lamprey. It originates as a single outgrowth which becomes subsequently branched, but in others it starts as a collection of nerves which unite to form a single bundle.

The SPINAL NERVES are similar to that of Branchiostoma. The dorsal and ventral roots remain separate and do not join as observed in gnathostomes. The first spinal nerve is the *hypoglossal*. The ventral root contains mostly the motor fibres that innervate the myotomes and the dorsal root possesses mostly the sensory fibres coming from the myotomes.

The sympathetic nervous system is represented by isolated nerve-fibres running in both the roots of the spinal nerves. This system is quite diffused and ganglionic formations are absent.

All the nerve-fibres of Lampreys are devoid of myelin sheath, as a consequence the rate of conduction through such nerves is very slow.

Sense organs

The organs of special sense are well-developed (Fig. 4.11). The sense organs are:

Eyes. Besides the normal paired eyes, lampreys possess a third unpaired eye called the *pineal* or *epiphysial eye*. All the three eyes developed from the diencephalonic region of the brain.

Pineal eye. The pineal apparatus is composed of two unequally developed sacs. The sacs are placed vertically one above the other. The dorsal one is the *pineal eye* and the ventral is the *parapineal organ*. The pineal eye is larger than the parapineal organ. Morphologically the pineal eye is placed on the right side, while the parapineal or parietal organ is on the left. Both the sacs are formed by the evagination of the roof of the brain and remain connected by two stalks with the epithalamic region of the diencephalon. Both the vesicles have a narrow lumen and the walls are composed of receptor-cells. The processes of the receptor cells project into the lumen and the nerve fibres are directed outwards. Besides the sensory cells, pigment and supporting cells are present in the retinal layers. The pineal apparatus has the same construction as the paired eyes, but the dioptic apparatus is not differentiated. The pineal organ has a nerve which enters into the posterior commissure that connects the posterior part of telencephalon and the parapineal organ has a nerve which enters into the left habenule.

The role played by the pineal apparatus is not known. The pineal apparatus has the power of response to change of illumination and thus essential for the initiation of movement. But its role in change of colour of the body is evident from the study on the ammocoetes larva. The ammocoetes larva has the property of changing its body colour. It becomes pale at night and dark during daytime. If the pineal apparatus is extirpated, the animal lacks the power of changing colour and becomes permanently dark. The pituitary gland liberates melanophore-expanding substance into the blood which is under the control of pineal eye.

Paired eyes. The paired eyes are typically built on the vertebrate plan. Each eye is placed in a socket which is formed of blood and lymph spaces. The eyes are not attached with the *conjunctiva*, but to the rim of the orbit. The eyes are moved by the *extrinsic muscles*. The *eye ball* is roughly spherical with a more or less flattened *cornea*. The *pupil* is round which is capable of little change in diameter. The cornea is composed of two layers separated by an intermediate gelatinous matrix. A special muscle of myotomal origin called the *cornealis muscle* helps in the process of accommodation (Fig. 4.11C). The cornealis muscle is attached with the outer layer of the cornea and the pull of this muscle flattens the cornea and also pushes the lens inwards.

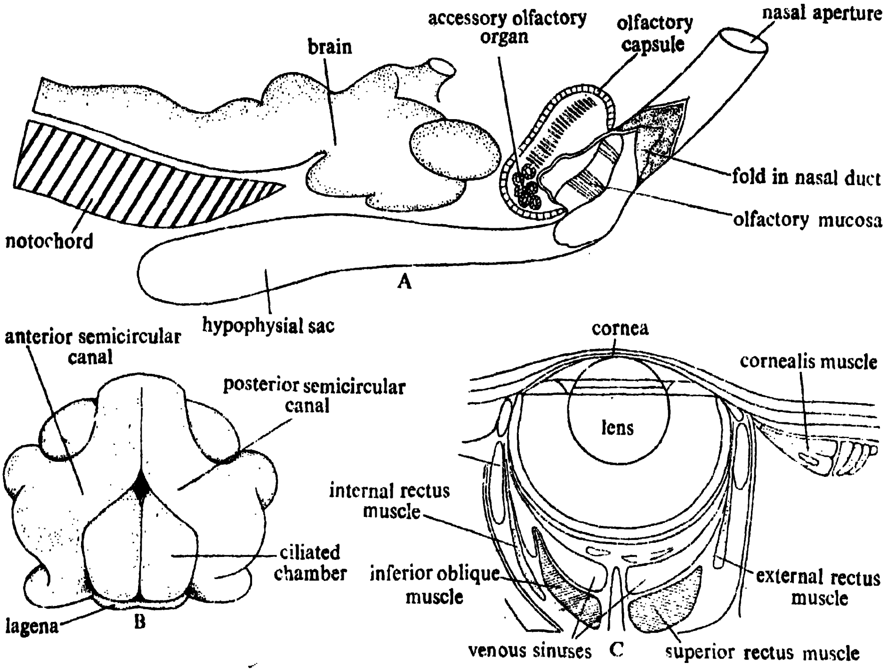

accessory olfactory organ
olfactory capsule
nasal aperture
brain
fold in nasal duct
olfactory mucosa
notochord
A
hypophysial sac
anterior semicircular canal
posterior semicircular canal
ciliated chamber
lagena
B
cornea
cornealis muscle
lens
internal rectus muscle
inferior oblique muscle
external rectus muscle
venous sinuses
C
superior rectus muscle

Fig. 4.11. Sense organs of *Petromyzon*. A. Showing the relationship between the nasohypophysial sac and brain. B. Membranous labyrinth. C. Section of an eye and its associated structures (after various sources).

Nasohypophysial sac. The external nostril leads into a round *nasal or olfactory sac* by a short duct. In vertebrates, the pituitary body develops from the invagination of the buccal epithelium. The lumen of the pituitary is devoid of any connection with the exterior, but in lamprey the lumen of the hypophysial rudiment becomes continuous with the nasal sac through a duct called the *nasohypophysial tube* (or *nasopalatine canal*). This tube extends posteriorly to a closed sac called the *hypophysial sac* (Fig. 4.11A). This sac lies below the brain and notochord and runs between the first pair of branchial pouches. The internal lining of the nasal sac has folded walls which contain olfactory receptors.

Ear. The auditory organs are represented by the *internal ear* or *membranous labyrinth* (Fig. 4.11B). Like that of other vertebrates, it is formed by the invagination of the wall of the head region and becomes subsequently cut off from the exterior. This is subdivided into a number of chambers by the infolding of the sac. The function of labyrinth in lamprey is not properly known and direct evidences regarding its responsiveness to sound are lacking.

Two *semicircular canals* are present which correspond the anterior and posterior canals of higher forms. Both these semicircular canals open into a large central sac called the *vestibule*. The vestibule is subdivided by a median fold into anterior and posterior *utricular chambers*. Below the utricular chambers there is a small anterior *sacculus* and a posterior *lagena*. The internal walls of all these chambers are ciliated and the cilia produce currents in the endolymph. Sensory areas are present in the utriculus, sacculus, lagena and ampullae. The *endolymphatic duct* is a short closed tube.

Lateral line sense organs. The lateral line receptors of lamprey consist of small patches of sensory cells and sensory papillae along certain lines. All the sensory papillae are exposed and are not enclosed in a canal. The line receptors are innervated by branches from the fifth and tenth cranial nerves. This system helps to detect and locate the disturbances in the aquatic environment. This system helps to search food, to avoid enemies and to orientate itself in running water.

Integumentary photoreceptors. In lamprey photosensitive cells are also present in the integument. These sensory cells are plenty in the tail region.

Excretory system

The adult functional kidney is of mesonephric type. The kidney develops from the nephrogenous tissue (*nephrotome*), i.e., the mesodermal region between the dorsal scleromyotome and the ventral lateral plate mesoderm. The nephrogeneous tissue differentiates into a series of segmental tubules along the anteroposterior direction. The first set of kidney in the larva is of *pronephros* type. The *pronephric tubules* open into a common *archinephric duct*. In the larval stage some anterior funnels of the pronephric tubules open into the pericardial cavity. Associated with the anterior end of each pronephric tubule, a tuft of blood vessels called the *glomerulus* is present. In course of development the pronephric tubules are replaced by the posterior set of *mesonephric tubules* which remain as the adult kidney. The pronephric tubules are represented in adult as a mass of lymphoid tissue. Between the two sets of the kidney, a separating portion is left where tubules are lacking.

The mesonephric tubules become greatly elongated and the anterior end of each tubule bears a double-walled *Bowmann's capsule* containing glomerulus. The tubules lack *nephrostomes*. Besides the tubules, fatty and lymphoid tissues also participate in the formation of kidney. In addition to the normal function of excretion, the kidneys participate in the manufacture and destruction of blood corpuscles. Each kidney remains attached to the dorsal wall of the coelom by peritoneal sheet. The *ureters* open posteriorly into the *urinogenital sinus*.

Reproductive system

The sexes are separate. The gonad is a large unpaired ridge occupying a median position to the mesonephros. The primordial germ-cells migrate to such gonadal ridge and transform into sperms or ova. The differentiation of gonad takes place quite lately as a consequence the ammocoetes larva possesses hermaphroditic gonad containing both oocytes and spermatocytes. The gonad extends almost the whole of the body cavity and lacks reproductive duct. The sex cells are discharged into the body cavity and leave the body by abdominal pores. These pores are present in the wall of the uriongenital sinus which open a few weeks before spawning.

The testis consists of many follicles containing male gametes which are liberated into the body-cavity. The ovary is composed of eggs which are covered by a layer of follicular epithelium. The eggs, when ripe, also rapture into the body-cavity. From the body-cavity both the eggs and sperms escape by way of abdominal pores. Fertilization is thus external.

Development

The egg is of *telolecithal* type containing a considerable quantity of yolk. The cleavage is *holoblastic* but unequal and results into the formation of an upper hemisphere of *micromeres* and a lower hemisphere of *macromeres*. Gastrulation occurs by invagination and the *blastopore* takes up a posterodorsal position and becomes converted into anus. The development of central nervous system is peculiar in lamprey. It develops as a solid cord or keel which hollows to form the lumen of the nerve cord. After about twenty-one days a young larval form hatches out as an AMMOCOETES LARVA. Existence of ammocoetes larva in the life-history of lamprey is significant.

Ammocoetes larva. The ammocoetes larva (Fig. 4.12) is a small transparent form of about 7 mm in length. The larval life persists for a considerable period of time and grows to an eel-like form measuring about 1.7 m. Structurally this larval stage exhibits an intermediate form between the cephalochordates and vertebrates. The suctorial buccal funnel is absent and the mouth is bounded by an oral hood resembling closely that of Branchiostoma (Fig. 4.12A). The major part of the larval phase is spent in burrow. The larva comes out occasionally to change the feeding habit. The mouth is surrounded by several branched buccal tentacles. The teeth are lacking. The velum is composed of a pair of muscular flaps which regulates the entry of water current into the pharynx. The paired eyes are vestigial and are hidden by the skin and muscles. The unpaired pineal eye is well-developed. The hypophysial and nasal sacs are poorly developed. The photoreceptors are abundant in the tail region which are connected with the lateral line nerves. The median dorsal fin is continuous with the caudal fin and is not divided into two parts by a median notch.

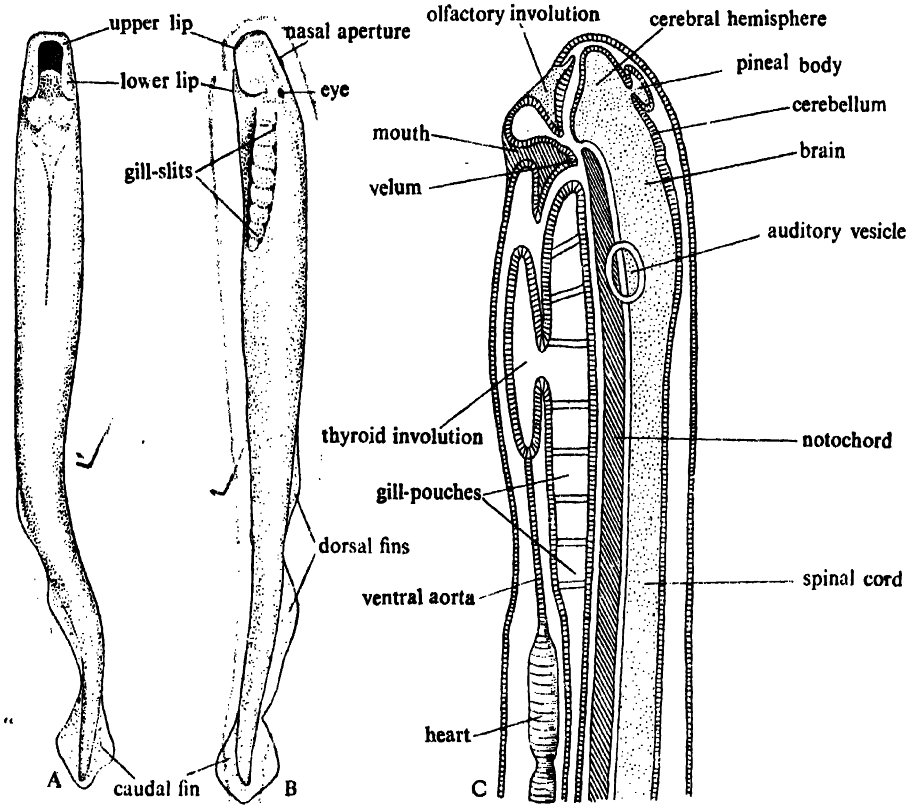

upper lip
lower lip
gill-slits
nasal aperture
eye
dorsal fins
caudal fin
A
B
olfactory involution
cerebral hemisphere
pineal body
cerebellum
brain
mouth
velum
auditory vesicle
thyroid involution
notochord
gill-pouches
ventral aorta
spinal cord
heart
C

Fig. 4.12. Anatomical organisation of Ammocoetes larva of *Petromyzon*. A. Ventral view. B. Lateral view. C. Diagrammatic longitudinal section (anterior part).

An *endostyle* is present in ammocoetes larva which is composed of two tubes. The floor of the tubes bears four rows of mucus secreting cells. The endostyle in ammocoetes larva is thus not an open groove as seen in Branchiostoma. The endostyle opens to the pharynx by a slit-like aperture and produces profuse quantity of mucus. The endostyle is connected with the ***hyper-pharyngeal groove*** by the ***peripharyngeal ciliated bands***. The feeding mechanism is peculiar and the food matters are separated from the feeding current in the pharyngeal cavity. The mucus produced by the endostyle entangles the food particles which are transported to the intestine by the action of the cilia in the pharynx. The *velum* and the elaborate muscular system of the branchial basket help in the maintenance of water current. The larva bears seven pairs of *branchial sacs* which open to the exterior by *gill-slits* (Fig. 4.12B). An additional branchial sac and gill-slit may be present. A *gall bladder* is present. The pronephros persists as the excretory organ.

The larval life of Ammocoetes larva is quite long and may extend 3 to 4 years. In favourable condition, preferably in winter, the larva metamorphoses into adult. During metamorphosis the larval characters are lost. A brief note on the important changes that occur during metamorphosis is given below: (1) The endostyle transforms into a thyroid gland below the pharynx. (2) The mouth becomes surrounded by suctorial buccal funnel with teeth, tongue and complex musculature. (3) The paired eyes become prominent and functional. (4) The nasal sac becomes internally folded which are connected with enlarged olfactory nerves. (5) The naso-hypophysial sac grows backwards. (6) The continuous median dorsal fin becomes divided into two parts by a median notch. (7)The velum becomes reduced and guards the opening of the respiratory tube only. (8) The oesophagus and the respiratory tube become independent canals. The gills develop into the sacs which open into the respiratory tube. (9) The skull and the branchial skeleton become specialised. (10) The gall bladder disappears. (11) The intestine becomes specialised. (12) The pericardial cavity becomes completely cut off from the coelom. (13) The pronephros degenerates and the mesonephros is formed. (14) The spinal cord becomes flattened. (15) The colour of the skin is changed from the yellow-brown to the adult texture. The larva migrates from the river to the sea to begin its adult life. The gonads become mature and the adult returns again to the river for the purpose of spawning. Thus to complete its life-cycle, lamprey exhibits an adult and a larval phase.

Example of Cyclostomata—HAGFISH

Several genera of Cyclostomes like *Myxine*, *Paramyxine* and *Eptatretus* (*Bdellostoma*) are commonly called the hagfishes. Although the lampreys and the hagfishes are included under the same class, the hagfishes show a wide range of variation in structural construction. This aspect has been dealt in the last part of this chapter.

Habit and habitat

Hagfishes are exclusively marine and spend most of the times in burrows excavated in sand or mud and usually devour the polychaete worms and dead fishes. They probably attack the dying or just dead fishes and suck out the whole content except the bones and skin. The sucking apparatus is highly developed in hagfishes. Hagfishes are nocturnal animals.

External structures

Hagfishes have slender eel-like body measuring from 45 cm (Myxine) to 1 m (Eptatretus) in length. An inconspicuous continuous *median dorsal fin* extends from the middorsal region of the body. It runs around the tail and proceeds anteriorly as a *ventral fin* up to the *cloacal opening*. The *caudal fin* is also narrow and is of *diphycercal* type (the cartilaginous epichordal or dorsal and hypochordal or ventral rays are similarly developed on the two sides of the notochord) like that of lampreys. The *mouth* is terminal in position and is bounded by delicate *lips*. The buccal cavity is more extensive than that of lampreys, but the buccal funnel is absent. There are about three or four pairs of *tentacles* around the edge of the mouth (Fig. 4.13A). The tentacles are supported by skeletal rods. Just on the dorsal side of the mouth there is a curved large *median tooth*. There are two rows of teeth on the tongue. The single nostril opens terminally close to the mouth. The *nasohypophysial tube* opens into the buccal cavity. The paired eyes are rudimentary and functionless. The number of external openings of gill-pouches varies from 1 to 15 pairs. In Myxine, the efferent ducts from the six gill-pouches of one side unite to form a common duct which opens to the exterior by a single slit (Fig. 4.13B). So in Myxine only one pair of *gill-slits* is visible. But in Eptatretus there exist thirteen to fifteen separate external gill-slits on each side of the body (Fig. 4.13E). There are rows of minute openings of the mucous glands specially on the ventral side of the body.

Body wall and musculature

The integument, like that of lampreys, is soft and lacks exoskeleton. The *epidermis* contains special types of '*thread cells*' in hagfishes (Fig. 4.14). Each such cell contains a continuous fibrous proteinaceous thread, which after release absorbs water to form a thick coating of mucus over the body.

The muscles in the body are arranged in myomeres. But in hagfishes, the myotomes are undivided, i.e., the myotomes of one side alternate with those of the other side of body. The 'tongue' is associated with an intricate system of muscles.

Locomotion

The hagfishes are sluggish animals and remain buried in the sandy bottom. The power of locomotion is comparatively poor because of the feeble development of the body musculature. However, the mechanism of locomotion in hagfishes is similar to that described in lampreys.

Skeletal structures

The SKULL is fundamentally similar to that of lampreys, but the roof is entirely membranous. The notochord is ensheathed by fibrous tissue, but the vertebral elements are absent. The nasal duct is covered by a fanestrated cartilaginous capsule and a series of rings which are attached with the cartilages of the skull.

The skeletal support of the branchial region is ill-developed. The branchial basket is represented by a few anterior branchial arches. The arches are the first *branchial* and *extrabranchial cartilages* and the second *extra branchial cartilages*. A pair of rudimentary cartilages supports the common gill-slit of Myxine.

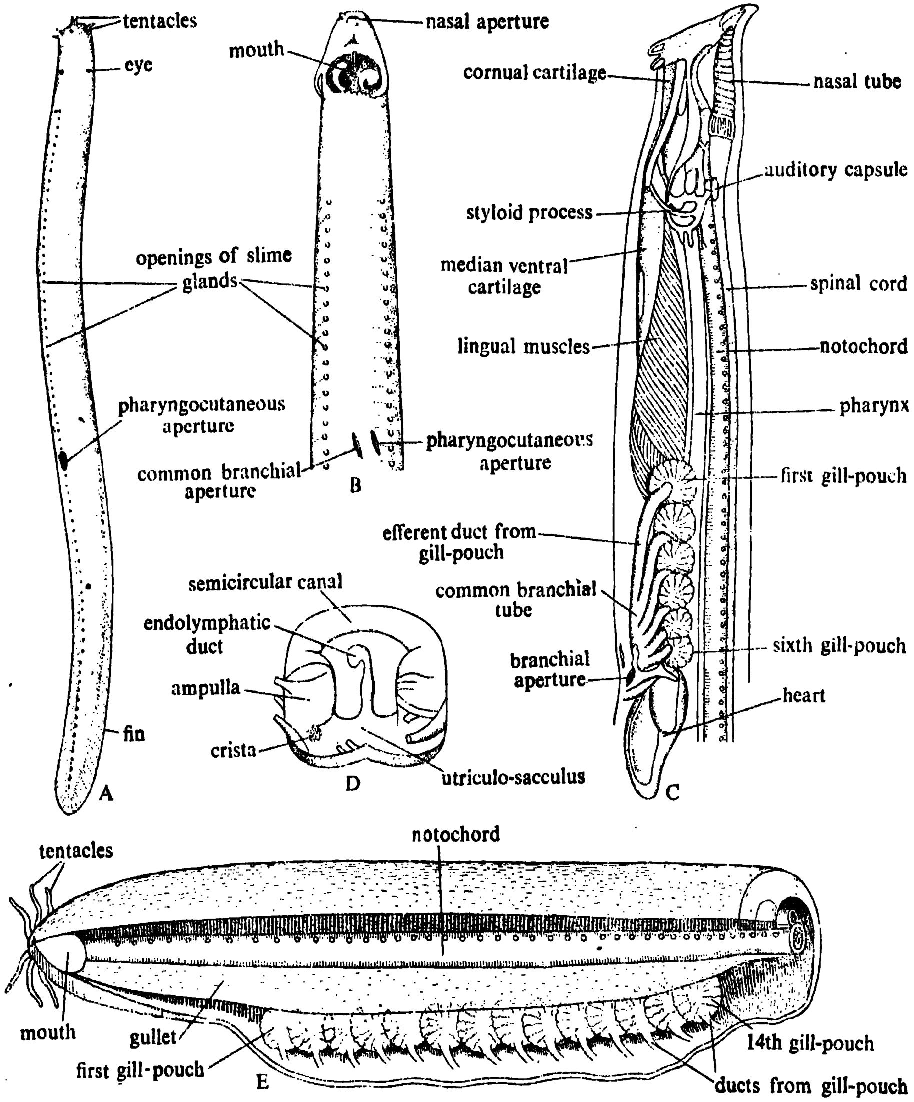

tentacles
eye
openings of slime glands
pharyngocutaneous aperture
fin
A
mouth
nasal aperture
common branchial aperture
pharyngocutaneous aperture
B
cornual cartilage
nasal tube
auditory capsule
styloid process
median ventral cartilage
spinal cord
lingual muscles
notochord
pharynx
first gill-pouch
efferent duct from gill-pouch
common branchial tube
sixth gill-pouch
branchial aperture
heart
C
semicircular canal
endolymphatic duct
ampulla
crista
utriculo-sacculus
D
tentacles
notochord
mouth
gullet
first gill-pouch
E
14th gill-pouch
ducts from gill-pouch

Fig. 4.13. Structures of the hagfishes. A. Dorsal view of an entire *Myxine*. B. Ventral view of the anterior end of *Myxine*. C. Diagrammatic longitudinal sectional view of *Myxine* to show the disposition of the internal structures. D. Membranous labyrinth of *Myxine*. E. A partly dissected view of *Eptatretus* to show the arrangement of gill-pouches. Note that each gill pouch communicates to the exterior through a separate exit.

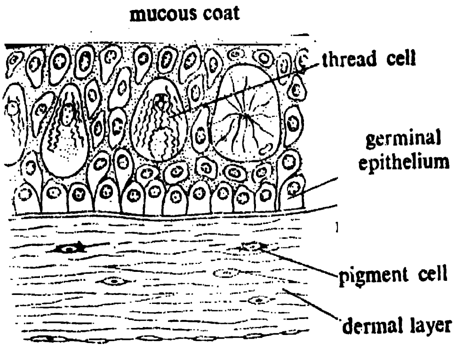


Fig. 4.14. Section of the skin of *Myxine*. Note the peculiar 'thread cells'.

Digestive system

The alimentary canal is a straight tube with a comparatively wide intestine. The 'tongue' is well-developed and is operated by elaborate tongue musculature. Two rows of small teeth are present on the 'tongue'. These teeth arise from the dental plate. The 'tongue' and sucking apparatus are well-developed. The stomach is a slightly dilated chamber. The intestine lacks the spiral valve. The liver is composed of two separate portions, one is dorsal and the other is ventral. A gall bladder is present. Two ducts, one coming from each portion of the liver, open independently into the gall bladder. A pancreas-like structure is represented by the aggregations of secretory tubules. It is comparable with that of lampreys.

Respiratory system

The gills are modified into the gill-pouches. The branchial region in hagfishes is restricted to the roundish respiratory enlargements (gill-pouches) which open into the pharynx. The number of the gill-pouches varies from six to fifteen pairs in hagfishes. Myxine has six pairs of gill-pouches while Eptatretus possesses thirteen to fifteen pairs of gill-pouches. In Myxine the gill-pouches do not open separately to the exterior as seen in the case of lampreys. Each gill-pouch produces an elongated efferent exit tube. Thus six exit tubes of one side unite to form a common canal which opens to the exterior by a single gill-slit (See Fig. 4.13C). So in Myxine only one pair of external gill-slit is present. But in Eptatretus, each gill-pouch opens separately, as a consequence thirteen to fifteen pairs of external gill-slits are present (See Fig. 4.13D). In hagfishes, a *pharyngo-cutaneous duct* is present immediately behind the last gill-pouch and on the left side. This is a communicating duct between the pharyngeal cavity and the exterior. The pharyngocutaneous duct opens into the left external branchial pore. This duct helps in the expulsion of larger particles from the pharynx and thus prevents the entry of such particles into the delicate gill-pouches.

Circulatory system

The heart is S-shaped and three chambered structure consisting of a sinus venosus, auricle and ventricle (Fig. 4.15). The conus arteriosus is absent, but the truncus is well represented. The arterial arches in hagfishes are almost similar to that of lampreys except that each aortic arch supplies the hemibranchs of a single gill-pouch (Fig. 4.16). The retention of left common cardinal (ductus Cuvieri) and the conversion of the right one into a portal heart supplying blood to the liver are the peculiar features in the circulatory system of hagfishes. The blood is iso-osmotic with the sea water. The blood forming lymphoid tissue is scatteredly observed in the submucous layer of the alimentary

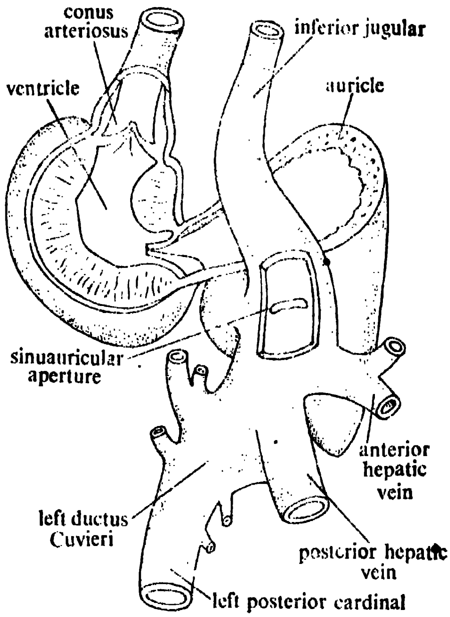


Fig. 4.15. Heart of *Myxine*. The chambers are dissected to show the internal organisation (after Jollie).

canal. The pronephros is also recorded to be one of the sources of formation of blood cells.

Nervous system

The nervous system of hagfishes is unlike that of the lampreys. The spinal cord is ensheathed exclusively by the fibrous tissue. The brain is devoid of any choroid plexus. The myelencephalon is large and the rest of the sectors of the brain are ill-developed in comparison to that of the lampreys. The olfactory lobes are larger. The ventricles of the brain are greatly reduced.

The cranial nerves are almost similar to that of lampreys with certain individual peculiarities. The oculomotor, trochlear and the abducens nerves are absent or extremely reduced as the consequence of degeneration of the corresponding eye muscles. The ninth and tenth nerves, like those of lampreys, are postcranial, i.e., the

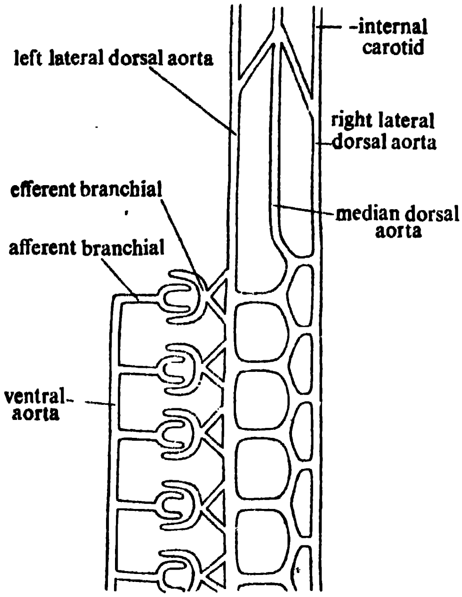

-internal carotid
left lateral dorsal aorta
right lateral dorsal aorta
efferent branchial
median dorsal aorta
afferent branchial
ventral aorta

Fig. 4.16. Schematic view of the erial arches of *Eptatretus* (after Jollie).

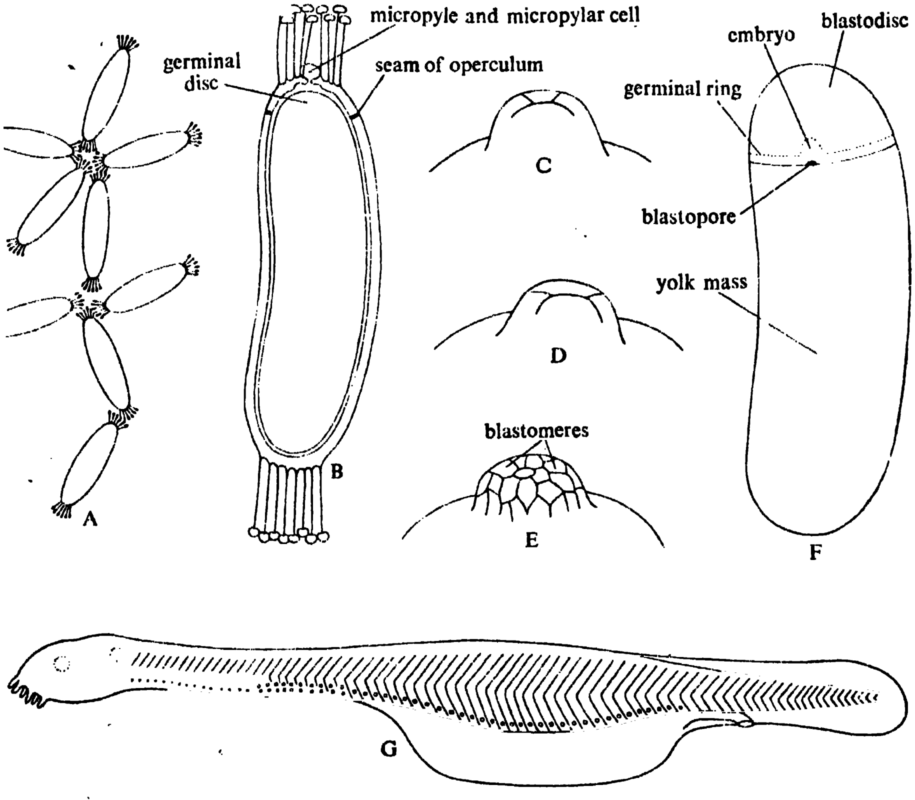

micropyle and micropylar cell
germinal disc
seam of operculum
embryo
blastodisc
germinal ring
C
blastopore
yolk mass
D
blastomeres
A
B
E
F
G

Fig. 4.17. Stages of development of *Eptatretus*. A. A cluster of eggs attached with each other by anchor filaments. B. An egg with anchor filaments on either pole. C. Four-cell stage. D. Showing early cleavage furrow. E. Early segmentating embryo. F. Showing the blastodisc cap at animal pole of the egg. G. Young immediately after hatching.

glossopharyngeal and vagus nerves do not emerge out from the brain. Besides these two posterior pairs of nerves, all other cranial nerves emerge out from the brain. The dorsal and ventral roots of the spinal nerves become united and are not separate as seen in case of lampreys.

Sense organs

The paired eyes are rudimentary and sunk below the skin. The eyes lack nerves and muscles. The pineal eye is absent. The ear has only one semicircular canal (See Fig. 4.13D) and this canal contains two ampullae one at each end. The nasohypophysial tube opens internally into the roof of the pharynx.

Excretory system

The pronephros is retained in adult hagfishes which is hardly marked off from the mesonephros. The pronephros lies dorsal to the pericardial cavity. In Eptatretus, the pronephric duct is present, but Myxine lacks such a duct. The pronephric tubules have no communication with the exterior. The functional kidney which is of mesonephric type is peculiar in having segmental disposition.

Reproductive system

The hagfishes are hermaphroditic. The anterior portion contains eggs and the hinder part is testis-like. They are protandric forms, i.e., the male gametes are produced prior to the maturation of the female gametes. The eggs are larger in size and are cylindrical in shape. The eggs are covered by a protective horny shell. The eggs are telolecithal types having hooked anchor filaments at either pole.

Development

The developmental events are known only in Eptatretus. The cleavage is meroblastic. The cleavage takes place at the animal pole of the fertilized egg and the embryo differentiates at the posterior margin of the blastodisc. The process of development resembles closely that of lampreys except in the initial stages of nerve tube formation. In hagfishes (as seen in *Eptatretus*), the development is direct, i.e., the larval life is absent. The stages of embryonic development of Eptatretus are shown in Fig. 4.17.

Lampreys AND **Hagfishes**—A comparative study.

A comparative study of the lampreys and hagfishes reveals many differences which are tabulated in Table Chordata-4.

TABLE CHORDATA—4

CHARACTERISTICS	LAMPREYS	HAGFISHES
1. Habit and Habitat	Live usually in sea and migrate to the rivers for spawning. The adults are semiparasitic but the larva leads independent life.	Exclusively marine and remains buried in sand and devours the polychaetes and other worms. They usually attack the dying and just dead fishes and enter inside the body (possibly through the mouth) and suck the whole contents leaving the skin and bones. They also eat the decomposed fishes.
2. Shape of the body	The body is cylindrical and stout.	The body is slender ("eel-like") and feeble.
3. Fins	The dorsal fin is divided into two portions by a notch. The caudal fin is well-represented.	The dorsal fin is ill-developed, narrow and undivided. The caudal fin is slightly developed.
4. Mouth	The mouth is subterminal in position due to the overdevelopment of the upper lip region to form a funnel-like structure.	Terminal in position and is surrounded by soft lips.

CHARACTERISTICS	LAMPREYS	HAGFISHES
5. Sensory tentacles around mouth	Absent.	Three or four pairs of tentacles are present around the edge of the mouth.
6. Buccal funnel	Present.	Absent.
7. Sucking device	Moderately developed.	Highly developed.
8. Nostril	Single nostril lies on the dorsal side of the head and occupies a median position.	Single nostril situated very close to the mouth and opens terminally.
9. 'Thread cells' in the skin	Absent.	Present.
10. Myotomes	The myotomes are separated into the dorsal and ventral portions by myosepta.	The myotomes are not separated, i.e., myotomes of one side alternate with those of the other.
11. Cartilaginous oral ring	Present.	Absent.
12. Lingual cartilage	Feebly developed.	Well-developed.
13. Roof of the skull	Mainly membranous with a narrow bar across the posterior region.	Exclusively membranous.
14. Teeth	Horny teeth are present in the buccal funnel and 'tongue'. The teeth present on the tongue are larger in size.	Small teeth are present on the 'tongue' along two rows.
15. 'Tongue'	Feebly developed.	Strongly developed.
16. Paired salivary glands	Present as a pair of pigmented sacciform structures within the hypobranchial muscles. True nature of these glands is controversial.	Absent.
17. Respiratory and digestive portions	The buccal cavity leads into two tubes, the dorsal one is the oesophagus and the ventral one is the respiratory tube.	There is no separation of the digestive and respiratory parts.
18. Respiratory tube	It is closed behind and the open anterior end is guarded by velum. The gill-pouches open directly into the respiratory tube.	Absent. The branchial region is restricted to the roundish enlargements called the gill-pouches which open into the pharynx.
19. Spiral valve in the intestine	Present.	Absent.
20. Liver, gall bladder and bile ducts	The liver is a massive conical structure. It is bilobed, but the lobes are joined. The gall bladder and bile ducts are present in larval stage, but usually disappear in adult.	The liver is divided into a dorsal and ventral portion. Gall bladder is present. Two bile ducts, one from each portion of the liver, open separately into the gall bladder. The two portions of the liver are not joined.
21. Branchial region	Voluminous.	Small and restricted.
22. Gill-pouches	Seven pairs of gill-pouches are present which do not open into the gut, but into the respiratory tube.	The number of gill-pouches varies from six to fifteen pairs. *Myxine* possesses six pairs of gill-pouches, while *Eptatretus* bears thirteen to fifteen pairs. The gill-pouches open directly into the gut.

CHARACTERISTICS	LAMPREYS	HAGFISHES
23. External gill-slits	Seven pairs in adult. An additional pair may be present in the larva.	One pair in *Myxine*, but thirteen to fifteen pairs in *Eptatretus*. In Myxine, the exit ducts from the gill-pouches unite to form two common tubes.
24. Pericardial sac	Thick-walled and supported by a cartilaginous skeleton.	Thin-walled and not supported by any skeleton.
25. Shape of R.B.C.	Circular in outline.	Elliptical in outline.
26. Blood forming tissue	Present in kidneys and below the spinal cord.	Scattered in the submucosa of the gut and pronephros.
27. Ductus Cuvieri	Only right one is present and the left is absent in adult, although both persist in the larva.	Both are present.
28. Aortic arches	Each arch divides and sends branches to the posterior hemibranch and anterior hemibranch of the adjacent gill-pouches.	Each supplies the hemibranchs of a single gill-pouch.
29. Nerve supply to heart	The heart gets the nerve fibres from the vagus nerve and contains nerve cells.	The nerves and nerve cells are absent in the heart.
30. Brain	Brain is comparatively well-developed.	Brain is simpler and degenerated.
31. Formation of central nervous system	The central nervous system is formed as a solid ectodermal keel which becomes hollow to form the neural tube.	In hagfishes (as studied in *Eptatretus*), it is formed from an open neural groove. The lips of the neural groove fuse and a hollow neural tube is cut off.
32. Olfactory lobe	Smaller.	Larger.
33. Choroid plexus	Present.	Absent.
34. Cranial nerves	Ten pairs of cranial nerves are present.	The oculomotor, trochlear and abducens nerves are absent.
35. Lateral line branch of vagus	Present and well-developed.	Absent.
36. Blood vessels in the spinal cord	There is no blood vessel within the spinal cord.	Blood vessels are present within the spinal cord.
37. Nerves to the eye-muscles	The eye-muscle nerves are present.	The eye-muscle nerves are absent.
38. Roots of the spinal nerves	The dorsal and ventral roots of the spinal nerves remain separate.	The dorsal and ventral roots are united.
39. Paired eyes	Functional and well-developed.	Rudimentary and sunk beneath the skin. The eyes are devoid of lenses and eye-muscles. The optic nerves are reduced.
40. Pineal eye	Present.	Absent.
41. Semicircular canals	Two semicircular canals each with an ampulla are present.	Only one semicircular canal with ampullae, one at each end, is present.
42. Nasohypophysial duct	Ends blindly.	Opens postriorly into the mouth cavity.

CHARACTERISTICS	LAMPREYS	HAGFISHES
43. Anterior lobe of Pituitary	Differentiated.	Undifferentiated.
44. Kidneys	The pronephros does not persist in adult. The mesonephros is the functional adult kidney. The mesonephric tubules are complicated and lack segmental disposition.	The pronephros is retained in adult. The functional kidney is of mesonephric type and simpler. The mesonephric tubules have segmental arrangement.
5. Urionogenital sinus	Present.	Absent.
6. Reproductive system	The sexes are separate in adult, but the ova may be present in the testis. In young Ammocoetes larva, the gonad is hermaphroditic in nature and contains both spermatocytes and oocytes.	The sexes are united. The anterior portion of the gonad acts as the ovary and the posterior part is testis-like.
47. Egg	The eggs are small and are devoid of horny shell. The eggs are ovoid in shape and are essentially isolecithal although an accumulation of large yolk materials is observed at the vegital pole.	The eggs are large and enveloped by cylindrical horny shell. The shell bears terminal hook-like processes. The eggs are elongated and typically telolecithal.
48. Segmentation	Holoblastic.	Meroblastic in Eptatretus.
49. Development	The development is accompanied by metamorphosis of the Ammocoetes larva.	The development is direct, i.e., the metamorphosis is unknown.

CLASSIFICATION

CLASSIFICATION IN OUTLINE

Class **Cyclostomata**

Subclass Petromyzontia, e.g., *Petromyzon, Lampetra, Entosphenus, Ichthyomyzon, Caspiomyzon, Geotria, Mordacia.*

Subclass Myxinoidea, e.g., *Myxine, Paramyxine, Eptatretus* (= *Bdellostoma*).

CLASSIFICATION WITH CHARACTERS

The class Cyclostomata is divided into two subclasses, Petromyzontia and Myxinoidea. These two subclasses are sharply distinguishable from each other as shown in table Chordata—4.

Subclass Petromyzontia

The members of this subclass are called the lampreys/lamper eels/lamperns/sand pride, etc. All these forms are included under one family Petromyzontidae. The subclass is characterised by having: (1) Two dorsal fins. (2) Seven pairs of gill-pouches opening into the respiratory tube. (3) Nasopharyngeal duct is closed behind. (4) Well-developed branchial basket. (4) Presence of two semicircular canals. (6) The dorsal and ventral roots of the spinal nerves remain separate. (8) Metamorphosis is present.

Examples: *Petromyzon* (common in the rivers of Europe, Japan, North America and western parts of Africa). *Entosphenus* (found in the western coasts of North America), *Ichthyomyzon* (abundant in the east coast of North America), *Lampetra* (the Eurasian fresh and salt water lamprey), *Geotria* (present in the rivers of Chile, Australia and New Zealand), *Mordacia* (occurs in Tasmania and Chile).

Subclass Myxinoidea

The representatives of this subclass are called the hagfishes. They are exclusively marine and possess many individual characteristics. These are: (1) The dorsal fin is continuous and feebly developed. (2) Six to fifteen pairs of gill-pouches are present and the number of gill-slits varies from one to fifteen pairs. (3) Nasopharyngeal duct opens posteriorly into the pharynx. (4) Branchial basket is ill-developed. (5) Only one semicircular canal is present. (6) The dorsal and ventral roots of the spinal nerves are united. (7) Metamorphosis is absent.

Examples: *Myxine* (inhabits the coast of South America), *Paramyxine* (common in Pacific ocean), *Eptatretus* or *Bdellostoma*-

(occurs in South Africa, New Zealand and Chile).

AFFINITIES AND SYSTEMATIC POSITION

The cyclostomes constitute a curious group of animals and represent the most primitive craniates that are living to-day. The anatomy of the cyclostomes exhibit many primitive, specialised and degenerative features which resemble other forms lowly or highly graded than this group. Because of the fact, the systematic position becomes a questionable issue.

Relationship with Limulus. Patten and Gaskell tried to draw affinities between *Limulus* and Ammocoetes larva of lamprey depending upon the superficial similarities in the respiratory apparatus. But the recent workers on this line, do not recognise such an unusual line of phylogenetic relationship.

Relationship with Branchiostoma. The cyclostomes show many anatomical resemblances with the Branchiostoma. The adult cyclostomes and Branchiostoma possess the following points of similarities: (1) The notochord is continuous. (2) Presence of segmental muscle blocks (myotomes) from the anterior to the posterior end of the body. (3) There are large number of gill-slits in Branchiostoma and specially in *Ebtatretus*. (4) Absence of gonoducts. (5) Straight alimentary canal. In addition to the above semblances, the ammocoetes larva of lamprey is strikingly similar to Branchiostoma. The adult cyclostomes show some anatomical advancement over Branchiostoma but the relationship with the ammocoetes larva needs consideration. The presence of continuous median dorsal fin, oral hood, endostyle and ciliated gut in both the forms led many Zoologists to postulate the idea that Branchiostoma, as seen to-day, represents a permanent neotenic larval form of some species of cyclostomes. But direct evidences in favour of this contention are lacking. The relationship with Branchiostoma does not advance our idea on the phylogenetic status of the cyclostomes, but their primitive organisation is amply clear from such a relationship. The cyclostomes possess many advanced characteristics over the Branchistoma which demand a higher rank than that of Branchiostoma.

Relationship with Craniata. Inclusion of the cyclostomes under the subphylum Craniata is unanimously accepted, because all the diagnostic craniate features are evident in them. These features are: (1) Presence of skull housing the brain. (2) Presence of vertebral column in a lowly developed condition. (3) The epidermis is multilayered. (4) Well-developed circulatory system with a contractile heart and blood is present. (5) Hepatic portal system is present. (6) The kidneys are usually of mesonephric types. (7) Thickening of the myotomal muscles on the dorsal side of the body. Despite of their construction on the basic craniate plan, the cyclostomes differ widely from the rest of the craniates by having numerous individual peculiarities; *viz.* (1) Absence of biting jaws. (2) Existence of the unconstricted notochord. (3) Rudimentary vertebrae are present. (4) The paired appendages are lacking. (5) Lack of true fin-rays. (6) Possession of a single median olfactory opening. These above mentioned features are quite uncommon in other craniates and have practically isolated the group from others. The presence of 'tongue', sucking mouth, horny teeth, sac-like gill-pouches with supporting branchial basket, dorsal nostril and the 'thread cells' in the hagfishes are possibly the adaptive features for the peculiar ways of life.

Relationship with Ostracoderms. The cyclostomes resemble closely the ostracoderms. The ostracoderm features present in the cyclostomes are: (1) The failure to evolve complex biting jaws. (2) Similar structure of brain and cranial nerves. (3) Similar auditory capsule. (4) The pouch-like branchial sacs. (5) Single median nasal aperture. But the lack of fossil records stand on the way of drawing any phylogenetic relationship between the groups. The cyclostomes differ from the ostracoderms, specially by the complete absence of bone and paired appendages and by having a few specialised features connected with the feeding habit. Despite of minor differences, the cyclostomes are regarded to be closely related to the ostracoderms. The specialised features are possibly emerged out of peculiar modes of feeding. Stensio (1927) has advocated the view that the cyclostomes have descended from the ostracoderms and during the process of descent the bony elements have been replaced by cartilages. Although positive evidences are lacking in favour of this idea, the ostracoderm relationship of the cyclostomes has solid basis to exclude all denials.

Relationship with Fishes. Although the cyclostomes and fishes are both primary aquatic vertebrates, the cyclostomes present many characteristics which are definitely primitive than the organisation of the fishes. The following features are regarded to be primitive in cyclostomes than in the fishes: (1) Presence of imperfect cranium. (2) Presence of poorly developed vertebrae. (3) Existence of a continuous median fin in Myxine and Ammocoetes larva. (4) The tail fin is of diphycercal type. (5) The heart is a tubular S-shaped structure. (6) The brain is lowly developed. (7) The ninth and tenth cranial nerves are not enclosed in the skull. (8) The nerves are non-medullated. (9) Poorly developed lateral line sense organ. (10) Persistent pronephric duct in hagfishes. (11) The respiratory organs are the gill-pouches. These characteristics testify the fact that the cyclostomes occupy a status much below that of fishes, although several attempts have been made to regard the cyclostomes as the degenerated fishes which have lost the paired appendages, jaws and many other structures during the process of transformation.

PHYLOGENETIC STATUS OF THE CYCLOSTOMES

The cyclostomes represent the most primitive forms amongst the craniates. They are lower in structural organisation than that of fishes but higher than that of Branchiostoma. The real relationship of the cyclostomes lies with the ostracoderms. The cyclostomes are regarded as the degenerative end-products of some groups of ostracoderms. The relative status of the two groups—lampreys and hagfishes within the class Cyclostomata becomes difficult to interprete. The lampreys possess many advanced characteristics than in hagfishes, *viz.* (1) The median fin is divided into two parts, but in hagfishes the fin is continuous. (2) The nostril is mid-dorsal in position, while in hagfishes it is terminal. (3) Cranium in lampreys is well-developed than the hagfishes. (4) Two semicircular canals are present in lampreys, but only one is present in hagfishes. (5) The vertebral elements are lacking in hagfishes, although these elements are present in lampreys in a lowly developed condition. (6) The hagfishes have functional pronephros which is absent in adult lampreys. (7) The lateral line organs are highly developed in lampreys. (8) The paired eyes are functional in lampreys which are non-functional in hagfishes. Besides these features, there are a few characters that are definitely more primitive in lampreys than in hagfishes. These characteristics are: (1) Ill-developed sucking apparatus. (2) The dorsal and ventral roots of the spinal nerves remain separate. (3) The eggs are minute. (4) The cleavage is of holoblastic type. (5) The development is indirect with the Ammocoetes larval stage. This larval stage shows many resemblances with the Branchiostoma. So the real status becomes more complicated to interprete. With all probabilities, the diversities in the two subclasses of the cyclostomata are due to their subsequent divergence from a common ancestral source. The lampreys and the hagfishes are the endproducts of two evolutionary lines converging back to the different orders of the ostracoderms. The lampreys are the direct derivatives of Cephalaspids and the hagfishes are the descendants of the Pteraspids. The probable phylogenetic tree is given in Fig. 4.18. The hagfishes are more primitive than the lampreys so far as the structural organisation is concerned. Although some features in lampreys are obviously more primitive in nature than hagfishes. the hagfishes are to be treated as lower in rank than the lampreys because majority of the features in them are degenerative.

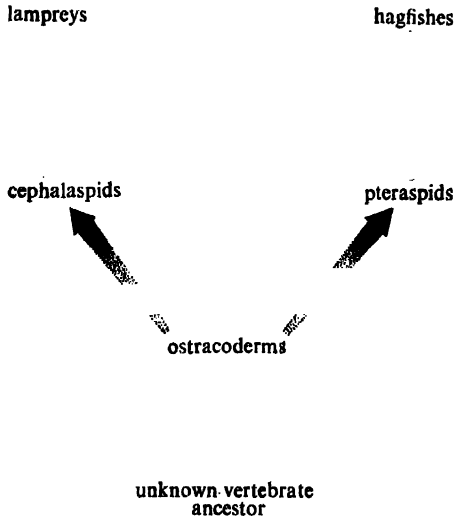


Fig. 4.18. Schematic representation of the probable phylogeny of the cyclostomes.

SUMMARY

1. The superclass Agnatha is represented by a group of animals which have failed to develop the biting jaws. The ostracoderms and cyclostomes are the members of the group. They constitute the earliest forms of backboned animals and furnish an interesting case of experimentation on feeding prior to the emergence of biting jaws in the vertebrate series.

2. All the agnathans are classified into two classes: Ostracodermi and Cyclostomata. Besides the absence of jaws, these two classes are united under a common superclass Agnatha or Monorhina by having a single median nostril, pouch-like gills and many other characteristics.

3. The class Ostracodermi includes the ostracoderms of the Ordovician rocks. All of them are extinct. They have fish-like bodies with heavy head armour. The gill-slits are rounded and the endoskeleton is moderately ossified.

4. The ostracoderms fall under four orders: Euphanerida, Pteraspidomorphi, Cephalaspidomorphi and Anapsida. *Jamoytius*, *Pteraspis*, *Cephalaspis* and *Birkenia* are some of the typical examples of the class.

5. The fossils of the ostracoderms are mostly recorded in the seas, but their progenitors were the inhabitats of fresh water near the estuaries.

6. The class Cyclostomata presents the living agnathous animals examplified by the lampreys and hagfishes.

7. The cyclostomes are characterised by having a common fundamental organisation. But the lampreys and hagfishes are sharply distinguishable from each other by a number of features. The common features are due to their common ancestry while the differences are due to their subsequent divergence in time and space.

8. The agnathans, in general, are considerably primitive in structural organisation than the fishes but higher than the cephalochordates. This transitional anatomical status makes the group extremely interesting.

9. The cyclostomes are regarded as the degenerated endproducts of two groups of ostracoderms in which the bony elements (present in the ancestral ostracoderms) have been replaced by cartilages. Although positive evidences are lacking, the ostracoderm relationship of the cyclostomes is significant.

10. Besides their anatomical peculiarities, the characteristics, habit and habitat of the extinct and extant agnathans furnish an idea about the biology of the early vertebrate forms.

CHAPTER 5

Phylum Chordata—FISHES

Fishes are the true aquatic vertebrates which exploit every nook and niche of the domain of water. The fishes are specially noted for their unimaginable number and bewildering forms. But all of them have a stream-lined body covered by scales and possess fins supported by fin-rays (Fig. 5.1). Fishes constitute the first group of animals that have developed the biting jaws in the phylogenetic history of the vertebrates. The aquatic environment has imparted tremendous influence on the life of the fishes. The biology of the fishes is so diverse, it is extremely difficult to give a concise account of the group. However, the present chapter deals with the biology of a few typical representatives with a special emphasis on their taxonomy and general organisation of the group.

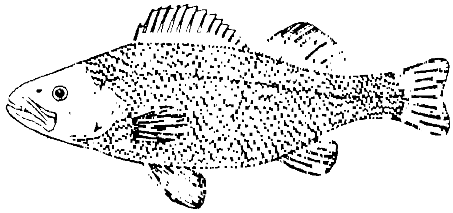


Fig. 5.1. A fish has a stream-lined body covered by the scales and moves by the fins.

IMPORTANT FEATURES

The fishes include a large variety of forms. All of them are built on a fundamental plan and possess the following common features: (1) The fishes are the primary aquatic vertebrates and the body is moulded to live in that particular condition of life. (2) The movement and equilibrium are maintained primarily by the paired and unpaired fins. The paired fins are the pectorals and pelvics while the unpaired ones are the dorsal, anal and caudal fins. The fins are supported by the true dermal fin-rays. (3) The body is covered by the dermal scales. (4) The organs of respiration are ordinarily the gills. (5) The notochord is virtually replaced by the development of the vertebrae which are either bony or cartilaginous in nature. (6) A single circuit venous heart is present. (7) Skull and the visceral arches are well-developed. (8) The internal ear with three semicircular canals is present. There is no middle ear. (9) The lateral line sense organs are well-developed and are mostly enclosed in a closed canal. (10) The dorsal and ventral roots of the spinal nerves are united. (11) Most of the nerves are medullated. (12) The kidney is of mesonephric type, although a few pronephric tubules may persist. (13) The allantoic bladder is absent.

OUTLINE CLASSIFICATION

The classification of fishes is a very difficult task in the science of Ichthyology (Gr. *ichthys*=a fish and *logos*=discourse). Due to the lack of complete fossil records and transitional forms, the division of the fishes into different groups is unsatisfactory. The older idea of the inclusion of all the fishes under a superclass PISCES is no longer followed in the recent times. All the fishes are classified directly into three classes—PLACODERMI, CHONDRICHTHYES and OSTEICHTHYES which occupy equal taxonomical ranks with the other classes of the gnathostomata. The following classes and subclasses of the fishes are recognised.

Class I. **Placodermi (Aphetohyoidea)**

Class II. **Chondrichthyes (Elasmobranchii)**

Class III **Osteichthyes**

There are six subclasses under the Class Placodermi. The subclasses are: (1) Acanthodii, (2) Arthrodira, (3) Petalichthyida,

(4) Antiarchi, (5) Rhenanida and (6) Palaeospodylia. The class Chondrichthyes includes two subclasses: (1) Selachii and (2) Bradyodonti. The class Osteichthyes contains two subclasses: (1) Actinopterygii and Crossopterygii.

Example of Cartilaginous fish—

SCOLIODON

The class Chondrichthyes embraces a large variety of cartilaginous fishes. To give a general idea of the class, the common example of the group, the dogfish is selected as an introductory type. There are several types of dogfishes available in the different parts of the earth. The typical Indian genus, *Scoliodon* is described below which is represented by about nine species, of which four are very common in the Indian seas.

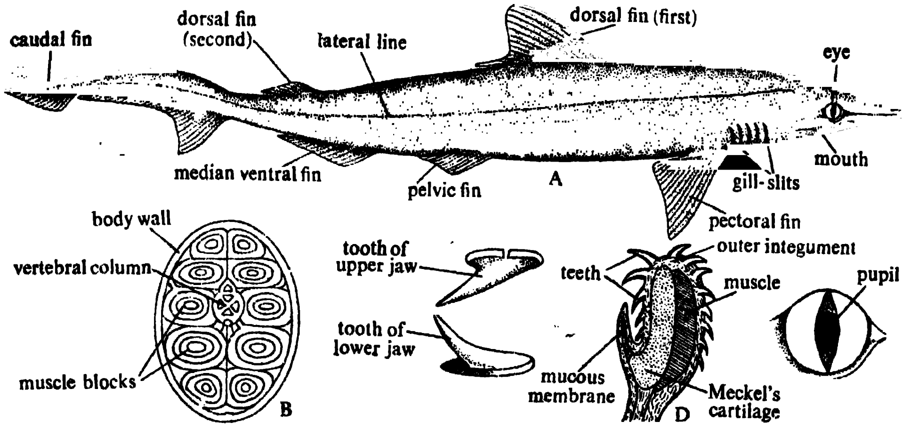


Fig. 5.2. Structural organisation of *Scoliodon*. A. External features of a female specimen. B. Transverse section through the tail region showing the arrangement of the muscle blocks. C. Disposition of a tooth in the lower and upper jaws. D. Sectional view of the lower jaw showing the gradual transformation of the placoid scales into the teeth. E. A front view of an eye (after Thillayampalam).

The four Indian species are: *Scoliodon sorrakowah*, *S. dumerilii*, *S. palasorrah* and *S. walbeehmi*.

HABIT AND HABITAT

Scoliodon is a marine fish. It is a predacious animal and depends on its swift movement for capturing the prey. It is primarily a fish eater and catches hold of the prey by its sharp teeth.

EXTERNAL STRUCTURES

Scoliodon is an elongated spindle-shaped animal. It has a laterally compressed body. A fully-developed specimen of the genus attains a length of about 60 cm. The body is divisible into *head*, *trunk* and *tail*. The head is dorsoventrally flattened and terminates anteriorly into a dorsoventrally compressed snout. The trunk is more or less oval in transverse section. It attains the maximum thickness in the middle region and gradually tapers posteriorly into a long tail (Fig. 5.2A). The tail is also oval in cross-section (Fig. 5.2B) and bears a *heterocercal* type of *caudal* fin, i.e., the posterior end of the vertebral column is bent upwards and lies in the dorsal or epichordal lobe. The *mouth* is a very wide crescentic aperture lying on the ventral side of the head near its anterior end. It is bounded by the upper and lower *jaws*, each is beset with one or two rows of sharply pointed and backwardly directed *teeth* (Fig. 5.2C) to catch the slippery prey. The teeth are replaced if these are broken. The teeth of Scoliodon are modified scales that cover its body and extend inside the jaws to serve as teeth (Fig. 5.2D).

Two prominent circular *eyes* are present. Each eye is provided with movable upper and lower *eyelids*. The third eyelid, the *nictitating membrane* can cover the whole eye in emergency. The *pupil* is a vertical slit-like aperture (Fig. 5.2E). The *nostrils* are placed one at each angle of the mouth. These are exclusively olfactory in function and have no connection with the mouth cavity. Each nostril is partly covered by a small fold of skin. Posterior to the eyes there are five vertical slits on each side. They are called the *gill* or *branchial slits*. The *cloaca* opens to the exterior by a *cloacal aperture* which is located in between the two pelvic fins. The cloaca is a common cavity, into which *anus, urinary* and *genital apertures* open. On each side of the cloaca lies the *abdominal pores*. The abdominal pores communicate with the coelom to the outside. A faint *lateral line* is present. Beneath this line an underlying canal is present which opens to the exterior by minute pores at intervals. Many pores called *ampullary pores* are also present on the head.

FINS

As in other fishes, Scoliodon bears unpaired and paired fins which are actually flap-like integumentary extensions of the body. These are flexible and are stiffened by cartilaginous *rods* or horny *fin-rays*.

Median unpaired fins. The fins under this category include two *dorsals*, one *caudal* and one *ventral* fin. The dorsal fins are triangular in outline. The anterior dorsal is larger and situated at about the middle of the body. The posterior dorsal is comparatively small and occupies a median position between the first dorsal and the tip of tail. The caudal fin has one ill-developed dorsal lobe (epichordal) and well-developed ventral lobe (hypochordal) which is divided into two parts. Two shallow depressions called the *caudal pits* are regarded the diagnostic features of the genus. These are present at the root of the tail, one at the dorsal surface another on the ventral. The median ventral fin is located in the midventral line and just anterior to the caudal fin.

Lateral paired fins. Two pectoral and two pelvic fins constitute the lateral paired fins. The pectoral fins are large and are situated posterior to the gill-clefts. The pelvic fins are much smaller. In females these are simple but in males each of them is connected with a copulatory organ called the *myxipterygium* or *clasper*. Clasper has a rod-like appearance having a dorsal groove leading to a siphon at its base.

SKIN

The integument is composed of an outer *epidermis* and an inner *dermis*. The epidermis is composed of epithelial cells intermixed with numerous unicellular *mucous glands*. In the young stage the epithelial cells are ciliated. But in adult the cilia are lost. The dermis is composed of three layers: (1) *Stratum laxum*, (*ii*) *Stratum compactum* and (*iii*) *Subcutaneous layer*. The stratum laxum is the outer layer and lacks fibres. The median layer is the stratum compactum which is fibrous in nature. The basal plate of the placoid scale is tied to this layer by fibres. The subcutaneous layer is variable in thickness and contains fine fibres arranged in a reticular fashion.

MUSCULAR SYSTEM

Between the endoskeleton and the skin there are closely packed muscles. The muscles are highly developed in the trunk and tail regions and exhibit distinct segmental arrangement. There are numerous myotomes which are separated from one another by partitions made up of tough connective tissue called the *myocommata*. The muscle-fibres run parallel to the length of the body in each myotome. In the head region, the muscles do not exhibit any sign of segmentation and have become specialised to control the movement of the jaws, pharynx and eyes. In the trunk region the muscles are greatly thickened on the dorsal side on each side of the vertebral column. Whereas in the tail region the muscles are equally developed round the vertebral column (See Fig. 5.2B).

SKELETAL STRUCTURES

The entire surface of the body is covered by oblique rows of *placoid scales* or *odontoids* (Fig. 5.3). A typical placoid scale has a *basal plate* made up of calcified tissue and remains embedded in the skin and a backwardly directed *spine* projecting out of skin. The basal plate is held in the dermis by Sharpey's and other fibres (Fig. 5.3E). A perforation is present at the base of the spine which communicates the *pulp cavity* of the basal plate with pulp cavity in the spine. The spine is composed of *dentine* coated externally with *enamel*. The nature of enamel is controversial. It is called the *fibrodentine*, because it is formed as the calcification of the fibrous material between the dentine and the enamel organ. The scales covering the body extend inside the jaws, where they act as the teeth. Placoid scale has dual source of origin and develops partly from epidermis and partly from dermis. The basal plate as well as the dentine of the spine are the derivatives of the mesoderm. The enamel is derived from the ectodermal enamel organ.

The ENDOSKELETON is composed exclusively of cartilage which may be hardened by calcification at places. It can be described under two heads: (1) The AXIAL SKELETON comprising the skull and the vertebral column and (2) the APPENDICULAR SKELETON consisting of the pectoral and pelvic girdles and the skeleton of the fins.

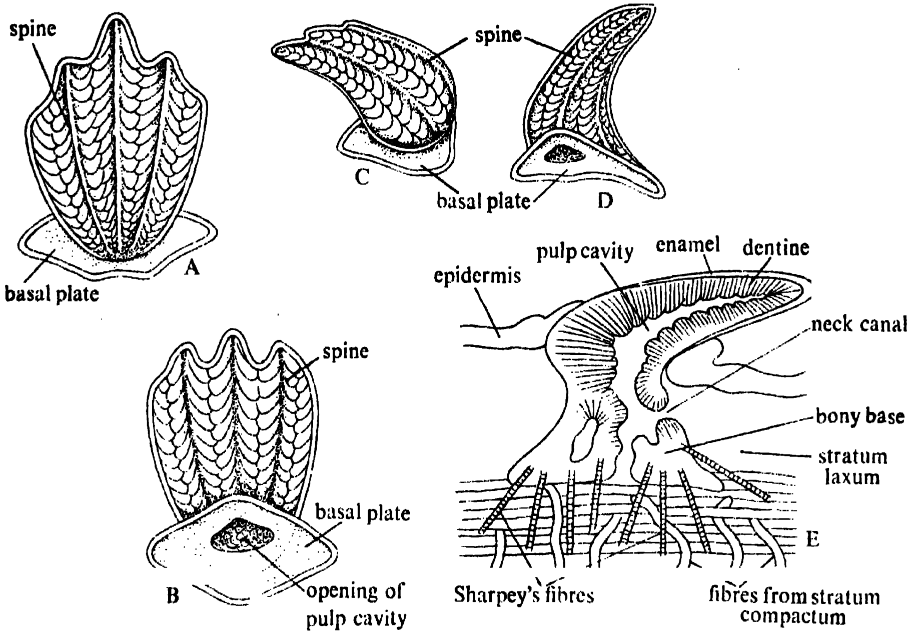


Fig. 5.3. Placoid scales of *Scoliodon*. A. Dorsal view. B. Ventral view. C. Dorsolateral view. D. Ventrolateral view. E. Diagrammatic sectional view (after various sources).

Axial skeleton. The SKULL is a simple cartilaginous casket. It consists of the *cranium*, four *sense-capsules* enclosing the auditory and olfactory organs and the *visceral skeleton* which form the jaws and supports the pharynx with gills. These three components of the skull remain intimately fused with each other (Fig. 5.4A, B). The cranium has four distinct regions: (1) The occipital region forms the posterior portion of the skull and contains a large *foramen magnum* through which the spinal cord passes down. An *occipital condyle* is present on either side of the foramen magnum. Above this foramen there is a median ridge called the *occipital crest*. (2) The auditory region is made of *auditory capsules* which remain firmly united with the cranium in adult. An oval depression between the two capsules is called the *parietal fossa*. The roof of the cranium has two large *fontanelles* on the dorsal side. (3) The middle region of the skull is composed of orbit. The margin between the roof of the cranium and the orbit is marked by the *supraorbital ridge*. A slender cartilage called the *preorbital process* partly encircles the orbit. Similarly a *postorbital process* emerges from the side of each postorbital cartilage and runs forward along the upper margin of the orbit. (4) The anterior or the *ethmoidal region* of the cranium is composed of the *olfactory capsules* and the *rostrum*. The two olfactory capsules are separated by the *internasal septum*.

The *visceral skeleton* comprises of seven half-hooped cartilaginous structures that encircle the buccal cavity and the pharynx. The first pair of the visceral arches gives rise to the jaws, the second pair to the hyoid arch and the rest of them support the gills. The first visceral arch is the *mandibular arch*. Each half of this arch divides into two parts, the upper part is called the *palatopterygoquadrate* which forms the upper jaw and the lower part is known as the *Meckel's cartilage* which forms the lower jaw. The second arch is called the *hyoid arch* which consists of three parts—a ventral *basihyal*, a lateral *ceratohyal* and a dorsal *hyomandibular*. The suspension of the jaws with the cranium is made through the hyomandibular and this type of suspensorium is called *hyostylic*. The rest of the visceral arches are known as the *branchial arches* which support the pharynx and the gills.

Vertebral column. The vertebral column is composed of a chain of cartilaginous vertebrae. The vertebrae develop around the notochord which is persistent (Fig. 5.4C). The vertebrae differ slightly along the length. A trunk vertebra is taken as the typical one.

Structure of a trunk vertebra. A trunk vertebra has a *centrum* that encloses the notochord. Above the centrum there is a *neural canal* through which the spinal cord passes down. The neural canal is roofed by *neural arch* which contains a short blunt *neural spine*. There is a pair of *transverse processes* which project from the centrum ventrolaterally. The centrum is *amphicoelous* (i.e., the centrum exhibits concavities on both the ends). The notochord is very narrow within centrum but becomes very much dilated in the intervertebral spaces (See Fig. 5.4C). The centra are reinforced by calcified fibrocartilage which forms four wedges and traverse the body of the centrum as a cross. Such centra are called *asterospondylous* types. The posterior vertebrae contain *haemal arch* which is present on the ventral side of the centrum. The haemal arch encloses the *haemal canal* enclosing the caudal artery and vein. The haemal arch gives a *haemal spine* to support the ventral lobe of the caudal fin. The posterior end of the vertebral column is bent dorsally.

Appendicular skeleton. The supporting skeleton of the fins (both unpaired and paired ones) constitutes the appendicular skeleton. The two dorsal fins and the ventral fin are provided with series of cartilaginous rod-like structures called the *pterygiophores* or *somactidia*. The distal ends of the somactidia bear double series of the *ceratotrichia* or horny *fin-rays*. Somactidia are absent in the caudal fin. Caudal fin is supported by the extensions of the neural and haemal spines.

Pectoral girdle and fin. The pectoral girdle is situated posterior to the last branchial arch and consists of two semicircular cartilages united with one another along the midventral line. The dorsal portion of each half is composed of a thick and rod-like *scapula* and the ventral portion is made up of a thin and flattened *coracoid* (Fig. 5.5A). At the junction of the coracoid and the scapula there are three facets for the articulation of the three basal cartilages of the pectoral fin called the *propterygium*, *mesopterygium* and *metapterygium*. The basal cartilages bear many radial cartilages (*radials*) supporting the pectoral fin.

Pelvic girdle and fin. The pelvic girdle comprises of a flattened cartilaginous rod situated along the transverse plane is front

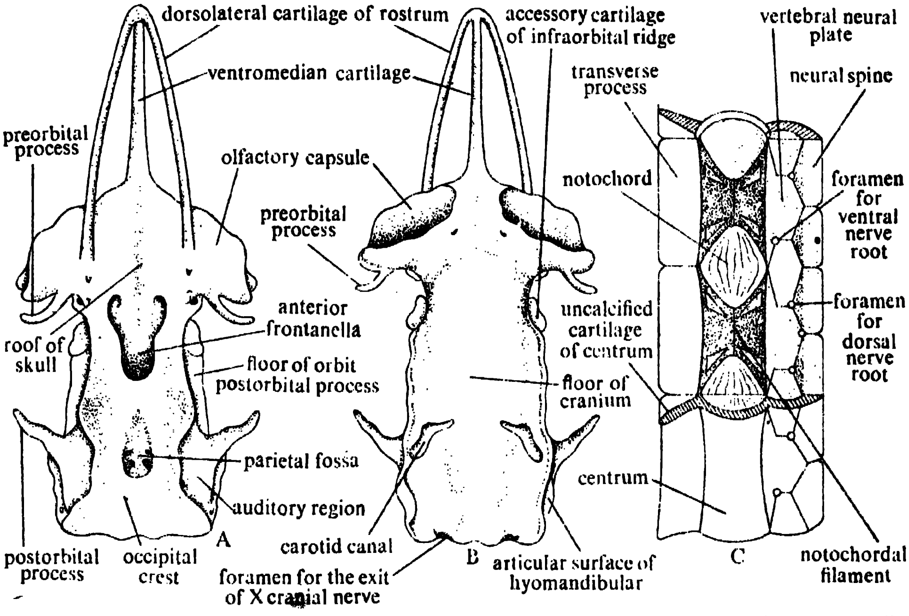

dorsolateral cartilage of rostrum
ventromedian cartilage
preorbital process
olfactory capsule
preorbital process
anterior frontanella
roof of skull
floor of orbit
postorbital process
parietal fossa
auditory region
A
carotid canal
postorbital process
occipital crest
foramen for the exit of X cranial nerve
accessory cartilage of infraorbital ridge
transverse process
notochord
uncalcified cartilage of centrum
floor of cranium
centrum
B
articular surface of hyomandibular
vertebral neural plate
neural spine
foramen for ventral nerve root
foramen for dorsal nerve root
C
notochordal filament

Fig. 5.4. Axial skeletal elements of *Scoliodon*. A. Dorsal view of the skull. B. Ventral view of the skull. C. Showing a part of the vertebral column of the trunk region. A portion of the vertebral column is cut longitudinally to show its internal organisation (after Thillayampalam).

of the cloaca. A curved basal cartilage called the ***basipterygium*** supports the radials of the pelvic fin (Fig. 5.5B). The basipterygium is attached anteriorly to the pelvic girdle. The radials at the distal ends contain small cartilages bearing the *ceratotrichia*.

In males each clasper is a tubular cartilage and grooved dorsally. Distally the groove terminates into a sharp *style* which is enclosed by two *sheathing plates*. At the upper end of the style lies a small *accessory cartilage*.

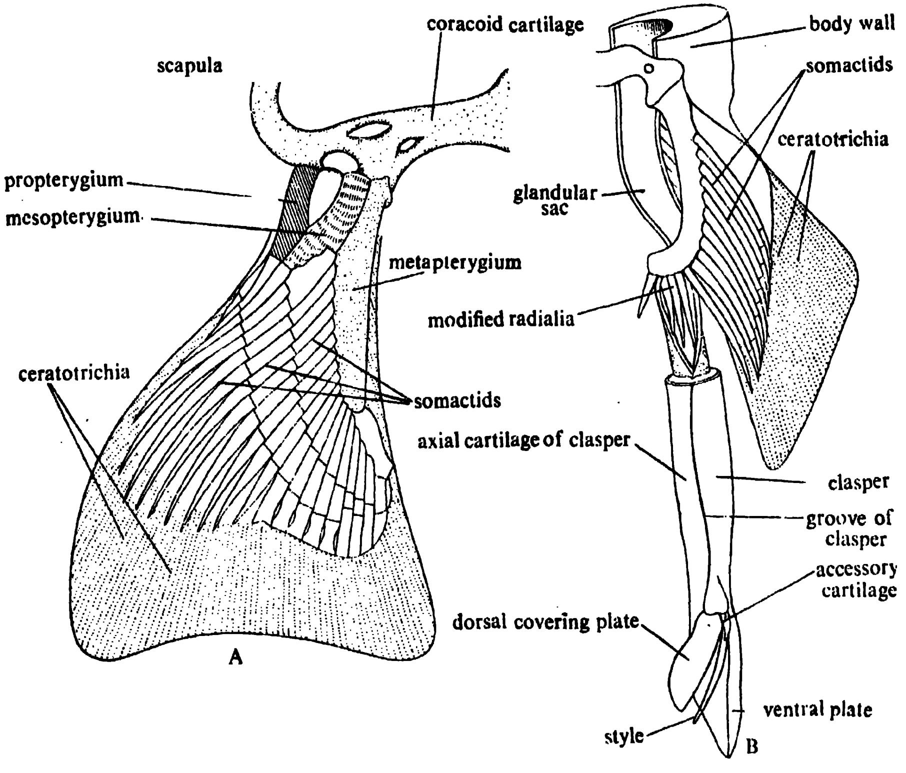

coracoid cartilage
scapula
propterygium
mesopterygium
metapterygium
ceratotrichia
somactids
A
body wall
somactids
ceratotrichia
glandular sac
modified radialia
axial cartilage of clasper
clasper
groove of clasper
accessory cartilage
dorsal covering plate
ventral plate
style
B

Fig. 5.5. Appendicular skeleton of *Scoliodon* (after Thillayampal[illegible]m). A. Half of the pectoral girdle and fin (ventral view). B. Half of the pelvic girdle and fin of a male (dorsal view).

LOCOMOTION

The movement of Scoliodon is caused by the activities of the myotomal longitudinal muscle fibres and also aided by movement of the fins. In the phylogenetic history of the fishes, the fins were primarily employed to raise the body off the bottom, but these become secondarily used in swimming by producing undulatory movements.

The longitudinal muscle-fibres composing the myotomes play the important role in swimming. The myotomes are placed on either side of the incompressible vertebral column which acts as a lever upon which the myotomes work. The contractility of the myotomes thus causes the bending of the body. During forward progression the contraction of the myotomes occurs along the anteroposterior direction in such a way that the waves of curvature pass down each side of the body alternately from the head to the tail. Such contraction is called the *metachronal contraction*. It has been calculated that about 54 waves are produced per minute during steady swimming. The controlling factors governing such contraction of muscles is not fully known. In Scoliodon, the transection of the spinal cord behind the medulla oblongata is capable of producing swimming movements for several days. This phenomenon suggests that rhythm of contraction is largely governed by the spinal cord, but the influence of brain on the whole process is yet unsolved.

The body and fins are specially modified to maintain an equilibrium in water during swimming. The dorsal fin is well-developed and helps to restore stability and helps in the restoration of equilibrium, if there is any deviation along the vertical axis of the body. The pectoral fins play a very important role in turning of the fish by the unilateral breaking with the pectoral fins. The pectoral fins also help to maintain stability in the vertical plane. The movable pectoral fins lift the head upwards and this is compensated by the heterocercal tail The hypochordal lobe is flexible and the epichordal part is rigid. The flexibility of the hypochordal lobe gives a vertical lift of the tail. The pelvic fins have no utility in locomotion and are usually help in reproductive function, specially in males.

COELOM

In Scoliodon, the coelom is spacious and divided into a smaller *pericardial* cavity and an extensive *abdominal* cavity. These two cavities are separated by the *septum transversum* and communicate with one another through *pericardioperitoneal canal* situated in the septum. The abdominal cavity contains the viscera (Fig. 5.6) and opens to the exterior through a pair of abdominal pores. The pericardial coelom houses the heart.

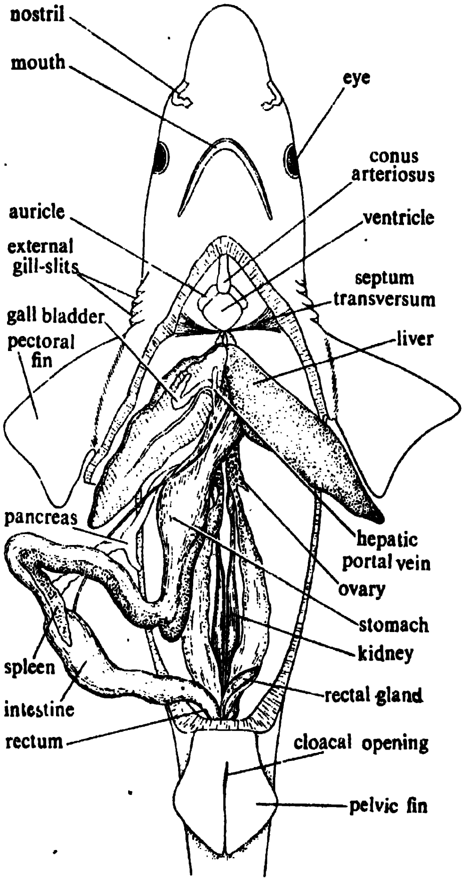


Fig. 5.6. Dissection of a female *Scoliodon* to show the position of the internal organs (after Thillayampalam).

DIGESTIVE SYSTEM

The digestive system consists of the *alimentary canal* and the *digestive glands.* The alimentary canal starts with the mouth and terminates in an anus.

The *mouth* leads into a spacious *buccal cavity* which is lined with mucous membrane. The floor of the buccal cavity becomes folded to form a nonmuscular and nongranular "tongue". The mucous membrane is very thick and rough due to the presence of dermal denticles or teeth. The teeth are very sharp and are obliquely placed (See Fig. 5.2C). The teeth are *homodont* (i.e., the teeth are similar in shape) and *lyodont* (possesses several sets of teeth functioning in succession).

The buccal cavity leads into *pharynx*. On either side of the pharynx there lie the internal openings of the *spiracles* and five branchial clefts. The mucous membrane of the pharyngeal wall contains numerous dermal denticles. The pharynx leads into a narrow *oesophagus*. The inner mucous membrane of the pharynx is raised to form longitudinal folds.

The oesophagus dilates posteriorly to form a large *stomach*. The stomach is highly muscular and is bent on itself to form a J-shaped configuration. The long limb of the stomach is continuous with the oesophagus and the shorter one passes into the *intestine*. The entrance of the oesophagus into the stomach is provided with a crescentic fold which serves as the valve. The long anterior limb is called the *cardiac stomach* and the short posterior limb is designated as the *pyloric stomach.* A small outgrowth often called the "blind sac" is present at the junction of the cardiac and pyloric limbs. The inner lining of the cardiac stomach is folded longitudinally like that of oesophagus (Fig. 5.7A). The internal lining of the pyloric stomach is mostly smooth though slight foldings are observed at the distal end. The pyloric valve, at the end of the pylorus, guards the entrance of it into a thick-walled small chamber called the *bursa entiana.* The bursa entiana is immediately followed by wide tubular *intestine* which becomes narrowed posteriorly as the *rectum*. The rectum opens into the *cloaca*. A tubular *caecal* or *rectal* or *digitiform gland* opens into the rectum.

The inner surface of the intestine becomes folded to form an anticlockwise spiral of approximately two and a half turns. This is called the *scroll valve* (Fig. 5.7B) which increases the absorptive surface of the intestine and also checks the rapid flow of digested food through the intestine.

The major digestive gland is the *liver* which is a massive yellowish gland and consists of two lobes. The lobes are united anteriorly. A thin-walled V-shaped *gall bladder* is present in the anterior part of the right

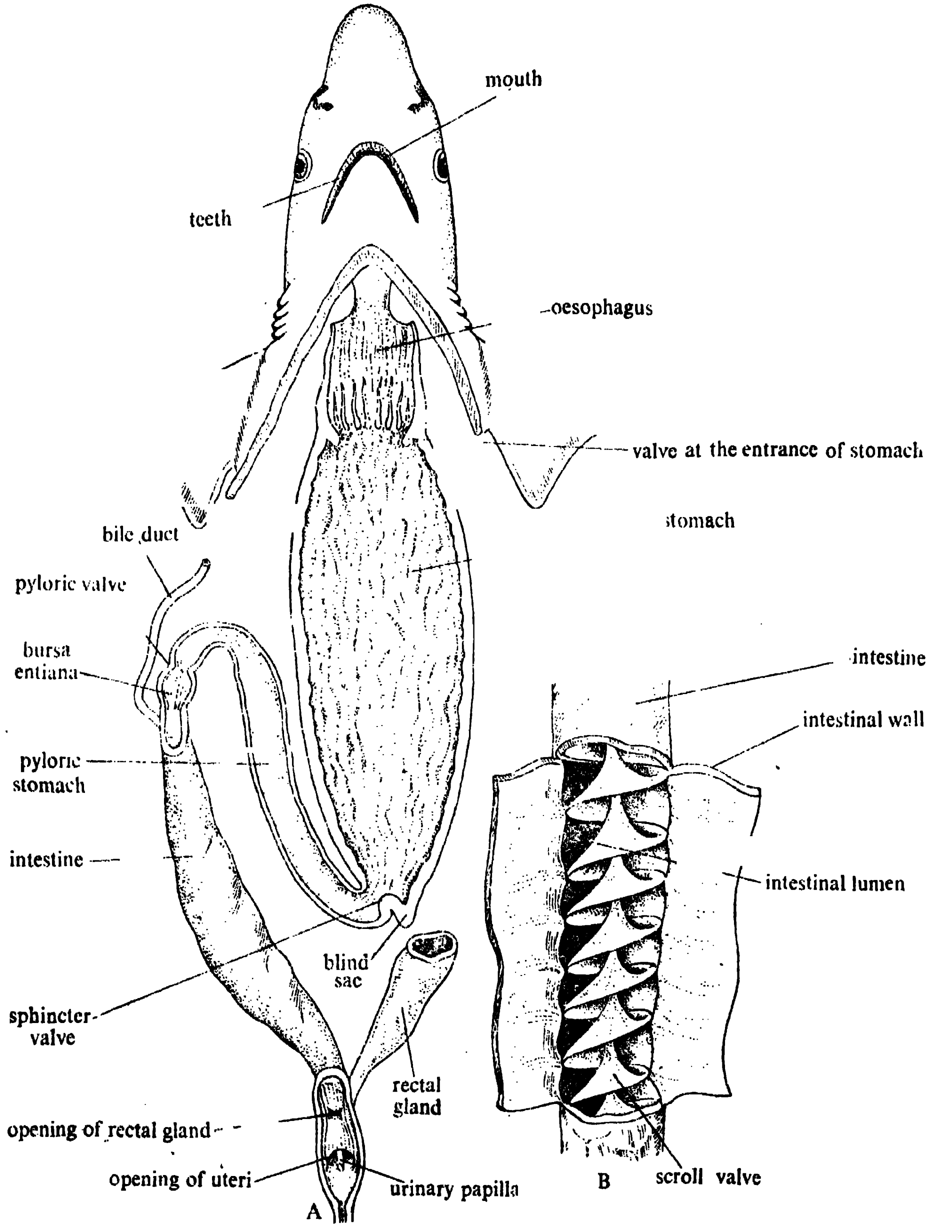

mouth
teeth
oesophagus
valve at the entrance of stomach
stomach
bile duct
pyloric valve
bursa entiana
pyloric stomach
intestine
sphincter valve
blind sac
rectal gland
opening of rectal gland
opening of uteri
urinary papilla
A
intestine
intestinal wall
intestinal lumen
B
scroll valve

Fig. 5.7. Digestive system of *Scoliodon*. A. Entire digestive tract. The oesophagus, stomach and the rectum are dissected to show the internal details. B. A portion of the intestine is cut open to show the scroll valve (after various sources).

lobe of liver. The *bile duct* receives few smaller ducts from the two lobes of the liver and opens into the anterior end of intestine near the commencement of the scroll valve. The *pancreas* is a pale compact irregular body and consists of a dorsal lobe situated parallel to the posterior part of cardiac stomach and a ventral lobe which remains closely attached to the pyloric stomach. The pancreatic juice is poured into the intestine by *pancreatic duct* situated opposite to the aperture of the bile duct.

The functional significance of *rectal gland* is not properly known. The rectal gland has a central cavity lined with cuboidal cells. It is highly vascular and composed of lymphoid tissue. It discharges a fluid into the lumen of the intestine but its actual role is not known. The buccal cavity possesses no such glands which can be compared with the salivary glands of higher vertebrates. The spleen is located dorsal to the distal end of the body of the stomach. The spleen is functionally associated with the circulatory system, but remains morphologically connected with the alimentary canal.

RESPIRATORY SYSTEM

The respiratory organs are the gills which are borne in the *gill pouches*. The structure of gill pouches differs in different dogfishes. Fig. 5.8B shows the organisation of gill pouch of *Brachaelurus*, a related genus of Scoliodon. There are five pairs of gill pouches, each of which communicates with the pharyngeal cavity by a large *internal branchial aperture* and opens to the outside by *exterior gill slits* (Fig. 5.8A).

The mucous membrane lining the gill pouches gives a series of horizontal *branchial lamellae*. The branchial lamellae are highly vascularised structures. Each gill pouch has an anterior set of branchial lamellae and a posterior set of branchial lamellae. The gill pouches are separated by interbranchial septum which projects beyond the branchial lamellae (Fig. 5.8C). The pharyngeal end of each interbranchial septum is supported by a visceral arch. Each arch supports the anterior set of lamellae of one gill pouch behind and the posterior set of lamellae of the next gill pouch. The first gill pouch lies between the hyoid and the first branchial arches and the last one is present between the fourth and fifth branchial arches.

There are two types of gills: (*i*) *Holobranch* or complete gill when a branchial arch bears two sets of gill lamellae and (*ii*) *Demibranch* or *hemibranch* or half gill when single set of gill lamellae is present. The hyoid arch supports only a demibranch and the first four branchial arches support holobranchs. The last branchial arch is gillless.

During respiration the floor of the buccal cavity is lowered and the mouth is opened. Then the water rushes in to fill the greatly expanded buccal cavity. The mouth is now closed and the pharynx contracts. The water then enters the gill pouches and goes out after gaseous exchange through gill slits. The spiracles are occasionally used as the accessory pathways for the entry of water for respiration instead of mouth when it is otherwise occupied.

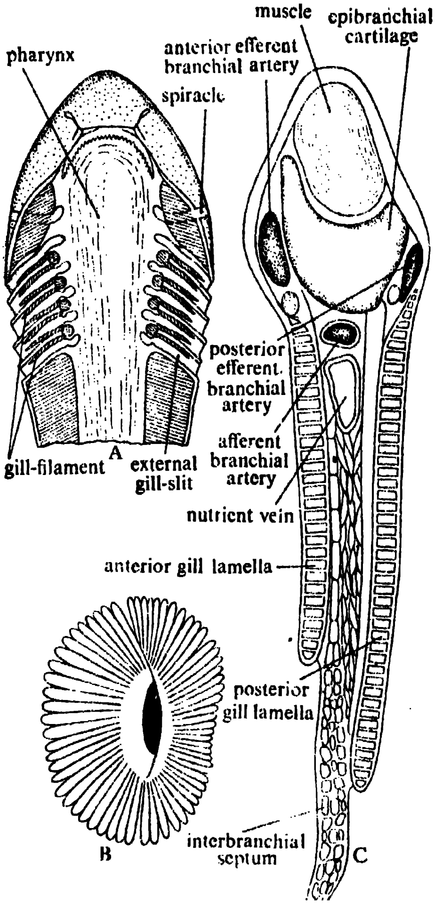


Fig. 5.8. Respiratory structures of dogfish. A. Dissection of the head showing the position of the gill apparatus of *Scoliodon*. B. Structure of a gill-pouch of *Brachaelurus*. C. Diagrammatic sectional view of a holobranch of *Scoliodon*.

CIRCULATORY SYSTEM

The circulatory system comprises of (*a*) the circulatory fluid called the blood, (*b*) the heart, (*c*) the arteries and (*d*) the veins.

BLOOD. The blood consists of a colourless plasma and corpuscles suspended in the plasma. Two kinds of corpuscles are encountered; the R.B.C. (or *erythrocytes*) and the W.B.C. (or *leucocytes*). Erythrocytes are oval bodies containing a nucleus. The haemoglobin is present in the erythrocytes. The leucocytes are amoeboid in structure.

HEART. The heart is a bent muscular tube and consists of the receiving parts, comprising of a *sinus venosus* and a dorsally placed *auricle* and the forwarding parts, consisting of a *ventricle* and a *conus arteriosus* (Fig. 5.9A). The heart is enclosed within the *pericardium*. The dorsal part of the pericardium is supported by the basibranchial cartilage. The heart is situated on the ventral side of the body between two series of gill pouches.

Receiving parts of the heart. The sinus venosus is a thin-walled tubular chamber. The sinus venosus is highly contractile and the beating of the heart originates from this part of the heart. Two great veins, the *ductus Cuvieri*, open into the *sinus venosus*, one on each lateral side. Two *hepatic sinuses* enter the sinus venosus posteriorly. The sinus venosus opens into the auricle by sinu-auricular aperture which is guarded by a pair of valves. The auricle is a large, triangular and thin-walled chamber situated dorsal to the ventricle but in front of the sinus venosus. The auricle communicates with the ventricle through a slit-like auriculo-ventricular aperture guarded by two lipped valves. The receiving chambers, the sinus venosus and the auricle receive the venous blood from all parts of the body.

Forwarding parts of the heart. The ventricle has a very thick muscular wall, the inner surface gives many muscular strands, thus giving it a spongy texture (Fig. 5.9B). It is an oval chamber and constitutes the most prominent part of the heart. The conus arteriosus is a stout median muscular tube arising from the ventricle. The lumen of the *conus arteriosus* is provided with two transverse rows of semilunar valves. To keep the valves in position the free ends of the valves are attached to the ventricular wall by fine tendinous threads called the *chordae tendinae*. The conus arteriosus is continued forward as the *ventral aorta*.

The function of heart is to receive the deoxygenated blood from all parts of the body and to pump it for aeration to the gills. Such a type of heart is designated as the venous or branchial heart, because only deoxygenated blood circulates through its different parts.

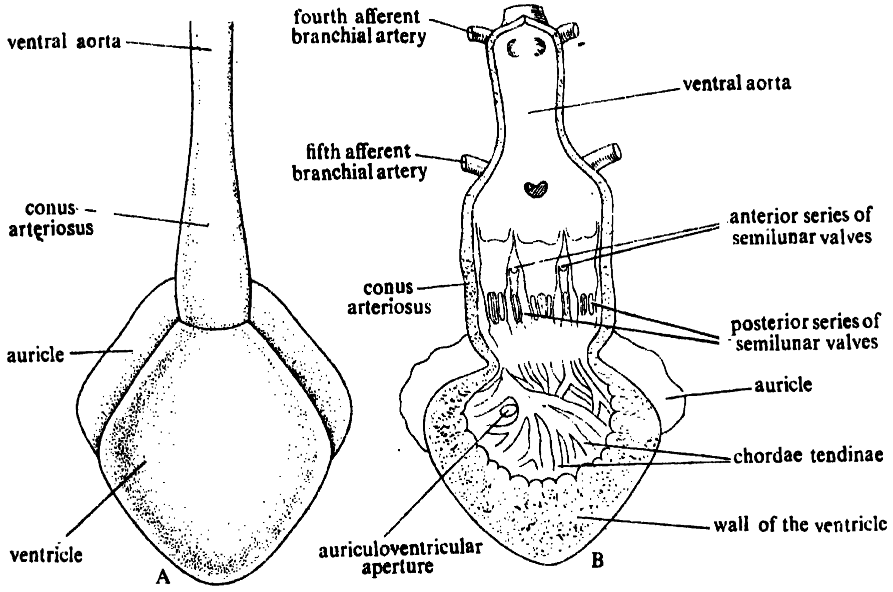

ventral aorta
conus arteriosus
auricle
ventricle
A
fourth afferent branchial artery
ventral aorta
fifth afferent branchial artery
anterior series of semilunar valves
conus arteriosus
posterior series of semilunar valves
auricle
chordae tendinae
wall of the ventricle
auriculoventricular aperture
B

Fig. 5.9. Heart of *Scoliodon*. A. An intact heart showing the position of different chambers. B. Diagrammatic longitudinal sectional view of the heart (after Thillayampalam).

ARTERIAL SYSTEM

The arterial system of Scoliodon is divided into two distinct categories of arteries. These are: (1) the afferent branchial arteries arising from the ventral aorta which bring deoxygenated blood to the gills for oxygenation and (2) the efferent branchial arteries originating from the gills convey oxygenated blood to the different parts of the body (Fig. 5.10).

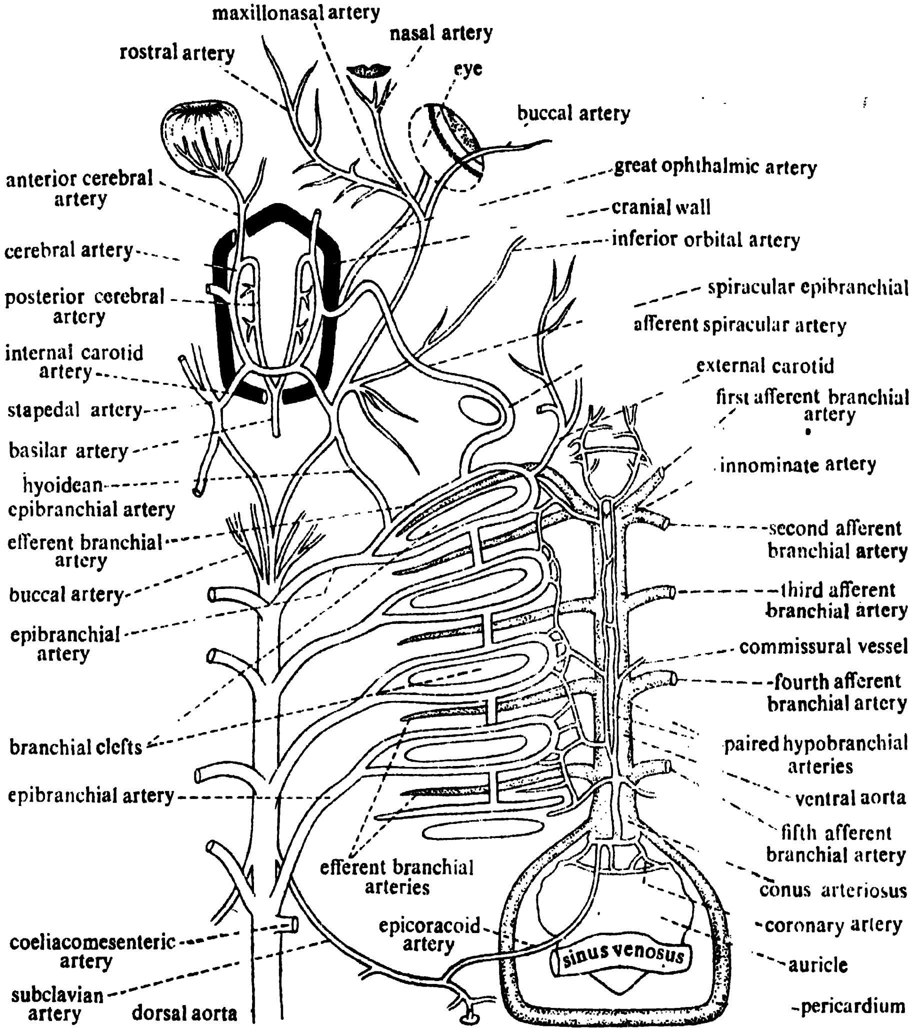

maxillonasal artery
rostral artery
nasal artery
eye
buccal artery
anterior cerebral artery
great ophthalmic artery
cranial wall
cerebral artery
inferior orbital artery
posterior cerebral artery
spiracular epibranchial
afferent spiracular artery
internal carotid artery
external carotid
stapedal artery
first afferent branchial artery
basilar artery
innominate artery
hyoidean epibranchial artery
efferent branchial artery
second afferent branchial artery
buccal artery
third afferent branchial artery
epibranchial artery
commissural vessel
fourth afferent branchial artery
branchial clefts
paired hypobranchial arteries
epibranchial artery
ventral aorta
fifth afferent branchial artery
efferent branchial arteries
conus arteriosus
epicoracoid artery
coeliacomesenteric artery
coronary artery
sinus venosus
auricle
subclavian artery
dorsal aorta
pericardium

Fig. 5.10. Disposition of the afferent and efferent branchial arteries and their branches in *Scoliodon* (after Thillayampalam).

Afferent Branchial Arteries. The *ventral aorta* is situated on the ventral surface of the pharynx and extends upto the posterior border of the hyoid arch. The ventral aorta divides into two branches called the *innominate arteries* which again bifurcates into the *first* and *second afferent branchial arteries.* The third, fourth and fifth afferent arteries arise from the ventral aorta. Each afferent branchial artery arises from the ventral aorta by independent opening except the anteriormost pairs which arise by a common opening.

Efferent Branchial Arteries. The afferent branchial arteries break up into capillaries in the gills. From the gills the blood is collected by *efferent branchial arteries.* There are nine pairs of efferent branchial arteries and these are equally distributed on each side. The first eighth arteries form a series of four complete loops around the first four gill slits and the ninth efferent branchial artery collects blood from the demibranch of the fifth gill pouch and from where blood is poured into the fourth loop. In addition to short *longitudinal connectives* connecting the four loops, these are further connected with each other by a network of longitudinal *commissural vessels* called the *lateral hypobranchial chain*. From each efferent branchial loop arises an *epibranchial artery*. The four pairs of epibranchials join in the mid-dorsal line to form the *dorsal aorta*. The ninth efferent branchial artery has no epibranchial branch but joins with the eighth efferent branchial artery.

Anterior arteries. The head region gets the blood supply from the first efferent branchial artery and partly from the proximal end of the dorsal aorta. Arteries from the *first efferent branchial* (*hyoidean efferent*) are: (*a*) the *external carotid*, (*b*) the *afferent spiracular* and (*c*) the *hyoidean epibranchial* which in turn receives a branch from dorsal aorta. The external carotid artery originates from the first collector loop and divides into a *ventral mandibular artery* giving branches to the muscles of the lower jaw and a *superficial hyoid artery* which supplies the second ventral constrictor muscle, the skin and the subcutaneous tissue beneath the hyoid arch. The afferent spiracular artery after originating from the middle of the hyoidean efferent, proceeds forward as the *spiracular epibranchial artery* and enters the cranial cavity. Just before its entry into the cranial cavity it sends a *great ophthalmic artery* to the eye ball. Immediately after the entry to the cranium it joins with a branch from the internal carotid to form the *cerebral artery*. The cerebral artery immediately divides into an *anterior* and a *posterior cerebral arteries* which supply the brain. The hyoidean epibranchial artery runs forward and inward to the posterior border of the orbit and gets an anterior branch from the dorsal aorta. It divides immediately into: (*a*) the *stapedial artery* which gives off the *inferior orbital artery* and runs forward as the *superior orbital artery* supplying the six eye muscles and the superficial tissue above the auditory capsule. The *superior orbital artery* gives a large *buccal artery* which runs as the *maxillonasal artery*. The maxillonasal gives several arteries to the muscles of the upper jaw, the olfactory sac and the rostrum (*b*) the *internal carotid artery* passes inward and enters the cranium where it bifurcates into two branches. One of the branches unites with its fellow from the opposite side and the other branch unites with the stapedial.

Dorsal aorta and its branches. The dorsal aorta is formed by the union of epibranchial arteries. It runs posteriorly and is situated ventral to the vertebral column. It is continued upto the tip of the tail as the *caudal artery*. Along the anteroposterior direction the following arteries have their origin from the dorsal aorta: (1) Several *buccal* and *vertebral* arteries are given off anteriorly. (2) A pair of small *subclavian arteries* arises near to the origin of the fourth epibranchial arteries. The subclavian artery gets the *epicoracoid* artery on its way and divides into: (*i*) a *brachial artery* to the pectoral girdle and pectoral fin, (*ii*) an anterior *lateral artery* to the body musculature and (*iii*) a *dorsolateral artery* to the dorsal musculature. (3) A large *coeliacomesenteric artery* arises just behind the origin of fourth epibranchial artery. It divides into a smaller *coeliac artery* and a larger *anterior mesenteric artery*. (4) A *lienogastric* artery originates posterior to the coeliacomesenteric artery and gives off (*i*) an *ovarian* (in female) or *spermatic artery* (in male) to gonad, (*ii*) a *posterior intestinal artery* to the posterior part of intestine, (*iii*) a *posterior gastric* to the posterior part of cardiac stomach and (*iv*) a *splenic artery* to the spleen. (5) Series of paired *parietal arteries* emerge out behind the subclavian artery. Each parietal gives a *dorsal parietal artery* and a *ventral parietal artery*. The dorsal parietal artery supplies the dorsolateral musculature, the vertebral column, the spinal cord and the dorsal fin. The ventral parietal artery supplies the ventral muscles and the peritoneum. The ventral parietal gives *renal* branches to the kidneys. (6) A pair of *iliac arteries* extends to the pelvic fin as the *femoral arteries*.

Hypobranchial chain. A lateral hypobranchial chain is formed by a network of slender arteries arising from the ventral ends of the loop of the efferent branchial arteries. Four *commissural vessels* arises from the lateral hypobranchial chain which on the ventral wall of the ventral aorta unite to form a pair of *median hypobranchials* which communicate with one another by transverse vessels. Posteriorly the median hypobranchials unite to form a median *coracoid artery* which gives rise to the *coronary artery* and a *pericardial artery*. The pericardial artery gives off the common *epicoracoid artery* which in turn divides into left and right epicoracoid arteries each joining one subclavian artery.

VENOUS SYSTEM

The deoxygenated blood from the different parts of the body is returned to the heart by veins which form irregular blood sinuses throughout their courses (Fig. 5.11). The existence of extensive blood sinuses is a characteristic feature of the venous system of Scoliodon.

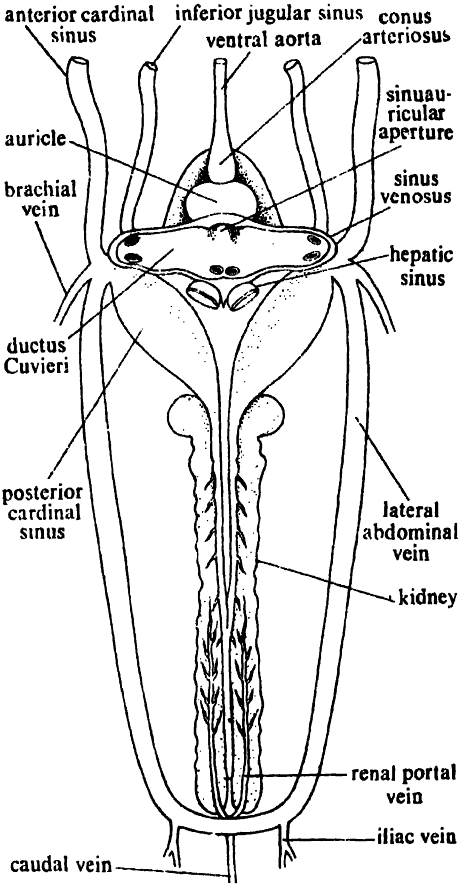


Fig. 5.11. Venous system of *Scoliodon* (after Thillayampalam).

The venous system is extremely complicated and is described under the following heads:

(A) CARDINAL SYSTEM. The blood from the anterior region of the body is returned to the heart by paired *jugular* and *anterior cardinal sinuses*. The blood from the posterior region is collected by a pair of *posterior cardinal sinuses*. The anterior and posterior cardinals unite on each side to form a transverse sinus called the *ductus Cuvieri*. (1) *Anterior cardinal system*. This system of veins return blood from the head region and consists of a pair of *internal jugular veins*. Each internal jugular vein is composed of the *olfactory sinus*, the *orbital sinus*, the *postorbital sinus* and the anterior *cardinal sinus*. The blood from the rostral region is drained by the *anterior facial vein* to the olfactory sinus and from there to the orbital sinus. The orbital sinus opens into the *anterior cardinal sinus* through the postorbital sinus. The anterior cardinal sinus enters the ductus Cuvieri. The anterior cardinal sinus receives the *hyoidean sinus* and five *dorsal nutrient branchial sinuses* from the gills. (2) *Posterior cardinal system*. The *caudal vein* collects blood from the tail region and proceeds forward through haemal canal. In the abdominal cavity, the caudal vein divides into *left* and *right renal portal veins* which break up into sinusoid capillaries in the substance of the kidney. Throughout its length, the renal portal vein receives small *parietal veins*. The *renal veins* collect blood from the kidney and unite to form the *posterior cardinal sinuses*. Two posterior cardinal sinuses open into the ductus Cuvieri.

(B) HEPATIC PORTAL SYSTEM. A large number of small veins carrying blood from the alimentary canal and its associated glands unite to form the *hepatic portal vein*. The hepatic portal vein receives the *lienogastric vein* and *anterior* and *posterior gastric veins*. Actually the hepatic portal vein is formed by the confluence of the *anterior* and *posterior intestinal veins*. The hepatic portal vein breaks up into capillaries in the liver. From the liver the blood is collected by another set of capillaries which unite to form two large *hepatic sinuses* opening into the sinus venosus.

(C) CUTANEOUS SYSTEM. This system consists of a *dorsal*, a *ventral* and two paired *lateral cutaneous veins*. The inferior lateral cutaneous vein joins with the lateral cutaneous vein near the anterior end of the pectoral fin. Each lateral cutaneous vein ultimately opens into the brachial vein.

(D) VENTRAL SYSTEM. This system comprises of two sets of veins – the *anterior ventral veins* pouring blood to the ductus Cuvieri through inferior jugular sinuses and the *posterior veins* which discharge through the subclavian vein. Each inferior jugular sinus is formed by the union of the *submental sinus* from the lower jaw, the *hyoidean sinus* and the *ventral nutrients* from the gills. Each inferior jugular vein opens to the ductus Cuvieri. The subclavian vein also opens to each side of the ductus Cuvieri.

Two large *lateral abdominal veins* are formed by a small *caudal vein* and two *iliac veins*. The lateral abdominal veins are connected posteriorly by a *commissural vein*. Anteriorly the lateral abdominal vein joins the brachial vein to form the subclavian vein which in turn opens to the ductus Cuvieri.

NERVOUS SYSTEM

The nervous system of Scoliodon comprises of (*i*) the central nervous system, (*ii*) the peripheral nervous system and (*iii*) the autonomous nervous system.

Central nervous system. The central nervous system includes the brain and the spinal cord.

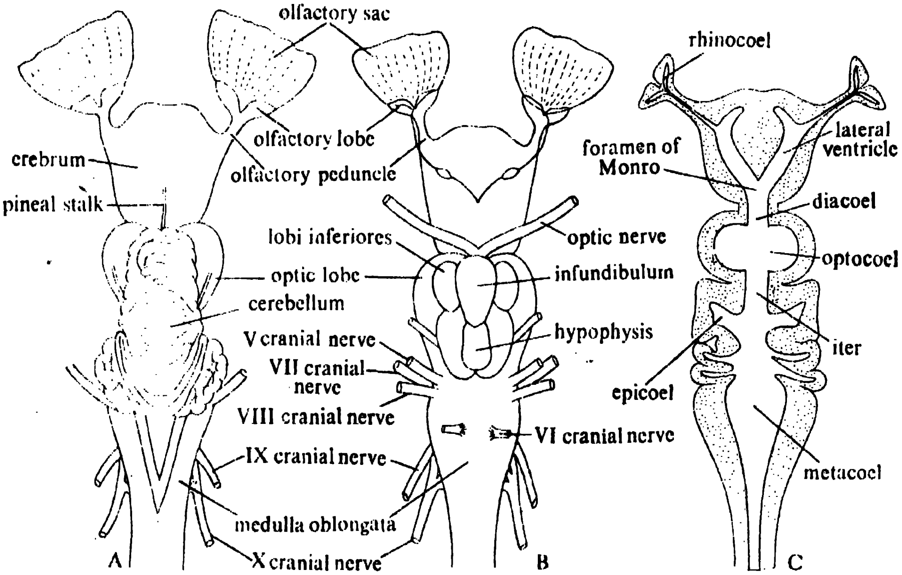

olfactory sac
rhinocoel
olfactory lobe
olfactory peduncle
crebrum
pineal stalk
foramen of Monro
lateral ventricle
diacoel
lobi inferiores
optic nerve
optic lobe
infundibulum
optocoel
cerebellum
V cranial nerve
hypophysis
VII cranial nerve
iter
VIII cranial nerve
epicoel
VI cranial nerve
IX cranial nerve
metacoel
medulla oblongata
X cranial nerve
A
B
C

Fig. 5.12. Brain of *Scoliodon*. A. Dorsal view. B. Ventral view. C. Diagrammatic longitudinal section. Note the position of the ventricles.

Brain. The brain is highly organised and shows many advancements over that of the agnathans. The brain is divided into three primary parts: (*a*) the forebrain or the *prosencephalon*, (*b*) the midbrain or *mesencephalon* and (*c*) the hindbrain or the *rhombencephalon*. The forebrain consists of a massive undivided *cerebral hemisphere*. The cerebral hemisphere is relatively larger than that of other fishes. From the anterior end of cerebral hemisphere arise two stout *olfactory peduncles*, each terminates into a large bilobed *olfactory lobe* (Fig. 5.12). The olfactory lobes lie close to the olfactory capsules. Each olfactory nerve is composed of many bundles of nerve fibres. The surface of the cerebrum is smooth and the walls are thick. A small opening called the *neuropore* is present on the midventral surface of the cerebrum. The posterior part of forebrain (diencephalon) is very short. The roof of the diencephalon is thin, nonnervous and contains the *anterior choroid plexus*. The lateral walls of the diencephalon form two thickened bodies called the *thalami*. A long and slender tube, the *pineal organ* or *epiphysis cerebri* projects from the roof of the diencephalon upto the membrane covering the anterior frontanella. The floor of the diencephalon (or *hypothalamus*) is well-formed. A hollow *infundibulum* is given off from the floor of the diencephalon. The infundibulum is dilated to form two oval thick-walled bodies called the *lobi inferiores* whose distal ends are produced into two thin-walled glandular sacs called the *sacci vasculosi*. The hypophysis is attached to the infundibulum. The *optic chiasma* lies in front of the infundibulum. The optic chiasma is formed by the decussation of the nerve fibres of the two optic nerves (Fig. 5.12B).

The midbrain is large and comprises of two round optic lobes. The optic lobes are situated behind the diencephalon. The floor and the side walls are relatively thicker.

The hindbrain consists of a highly

developed *cerebellum* and a *medulla oblongata*. The dorsal surface of the cerebellum produces many irregular convolutions. The cerebellum contains a small cavity. The cerebellum is divided into three lobes by two well-marked transverse furrows. The medulla oblongata is triangular and the anterior end gives a pair of hollow *corpora restiformia* with trace of convolutions in adult. Two corpora restiformia are connected by transverse nerve band. The roof of the medulla oblongata is nonnervous and bears the *posterior choroid plexus*.

The ventricles of the brain is moderately developed (Fig. 5.12C). The cerebral hemispheres contain narrow lateral ventricles. The third ventricle is extended forward about half the length of the cerebral hemispheres. The floor of the *fourth ventricle* is very much thickened. The fourth ventricle is large and extends dorsally into the cerebellum and is continuous behind with the cavity of the spinal cord. The *iter* (i.e., the communicating duct between the third and the fourth ventricles) is wider. Although the cerebrum is undivided, there are two lateral ventricles which are continued to the *rhinocoels* (cavity of the olfactory lobes).

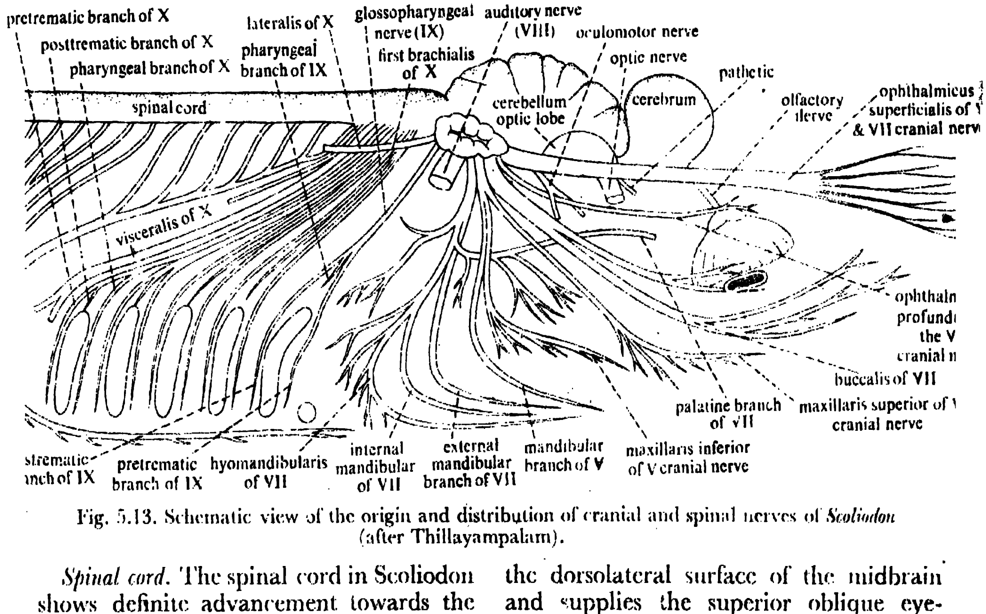

pretrematic branch of X
posttrematic branch of X
pharyngeal branch of X
lateralis of X
pharyngeal branch of IX
glossopharyngeal nerve (IX)
first brachialis of X
auditory nerve (VIII)
oculomotor nerve
optic nerve
pathetic
olfactory nerve
ophthalmicus superficialis of V & VII cranial nerv
spinal cord
cerebellum
optic lobe
cerebrum
visceralis of X
ophthaln profundi the V cranial n
buccalis of VII
palatine branch of VII
maxillaris superior of V cranial nerve
strematic anch of IX
pretrematic branch of IX
hyomandibularis of VII
internal mandibular of VII
external mandibular branch of VII
mandibular branch of V
maxillaris inferior of V cranial nerve

Fig. 5.13. Schematic view of the origin and distribution of cranial and spinal nerves of *Scoliodon* (after Thillayampalam).

Spinal cord. The spinal cord in Scoliodon shows definite advancement towards the plan of higher vertebrates. The gray matter is arranged into the dorsal and the ventral horns. The dorsal horns are united to form a single broad region, as a result the gray matter assumes a shape of an inverted 'T'.

PERIPHERAL NERVOUS SYSTEM. The peripheral nervous system comprises of the *cranial nerves* and *spinal nerves*.

CRANIAL NERVES

There are ten pairs of cranial nerves in all the fishes. An extra pair of anterior terminal nerves is present in Scoliodon. The first pair of cranial nerves is the *olfactory nerves* which originate from the olfactory lobes and innervate the olfactory sacs. Between the two olfactory lobes, there are two small nerves called the *terminal* or *preolfactory nerves*. These nerves emerge from the telencephalon and bear a ganglion called the *ganglion terminale* near the origin. These nerves supply the nasal septum and the external nostril. The second pair of cranial nerves is the *optic nerves* which, after the origin from the optic thalami, form the optic chiasma and supply the eyes. The third cranial nerve is called the *oculomotor nerve* which originates from the ventral surface of the mesencephalon and supplies the anterior, superior and inferior rectus and the inferior oblique muscles of each eye-ball.

The fourth cranial nerve is called the *trochlear* or *pathetic nerve* which arises from the dorsolateral surface of the midbrain and supplies the superior oblique eye-muscle. The fifth cranial nerve is the *trigeminal* which has three branches, (1) *ophthalmicus superficialis* which supplies the skin of the snout; (2) the *maxillaris* which is divided into the *maxillaris superior* supplying nerves to the skin of the upper jaw and *maxillaris inferior* innervating the posterior part of the upper jaw; (3) the *mandibularis* innervating the muscles of the lower jaw. Another nerve called the *ophthalmicus profundus* becomes secondarily associated with the trigeminal to supply nerves to the eye-ball and the dorsal surface of the snout (Fig. 5.13). The sixth cranial nerve is the *abducen* which supplies the posterior rectus muscle of the eye-ball. The seventh cranial nerve is known as the *facial* which divides into two branches—(1) the *ophthalmicus superficialis* branch like that of the fifth cranial nerve and (2) a bundle of mixed nerves which subdivides into three routes: (*a*) a *ramus buccalis* innervating the infraorbital canal of the snout, (*b*) a *ramus hyomandibularis* supplying nerves to the lower jaw and the throat and (*c*) a *ramus palatinus* giving nerve supply to the roof of the buccal cavity and the pharynx. The eighth cranial nerve is called the *auditory* which gives the *vestibular* and *saccular* branches to the internal ear.

The ninth cranial nerve is the *glossopharyngeal* which, in the region of the first gill-cleft, divides into a small *pretrematic nerve* and a large *posttrematic nerve*. These nerves supply branches to the pharynx, pharyngeal muscles and the mucous membrane surrounding the first gill-slit. The tenth cranial nerve is the *vagus* which arises by multiple roots and gives off many branches. The branches are: (i) the *branchial* nerves supplying the gills, (*ii*) the *visceral* nerves supplying the viscera including heart, lungs, liver, etc., and (*iii*) the *lateralis* supplying the lateral line sense organs and gives numerous branches along its course.

SPINAL NERVES

The spinal nerves arise from the spinal cord. Each has one *dorsal* and a *ventral root*. The dorsal root bears a ganglionic swelling. After emerging out of the vertebral column, the dorsal and the ventral roots unite to form a common mixed nerve. Each spinal nerve gives three branches such as, (*a*) *ramus dorsalis*, (*b*) *ramus ventralis* and (*c*) *ramus communicans* to join with the autonomous nervous system.

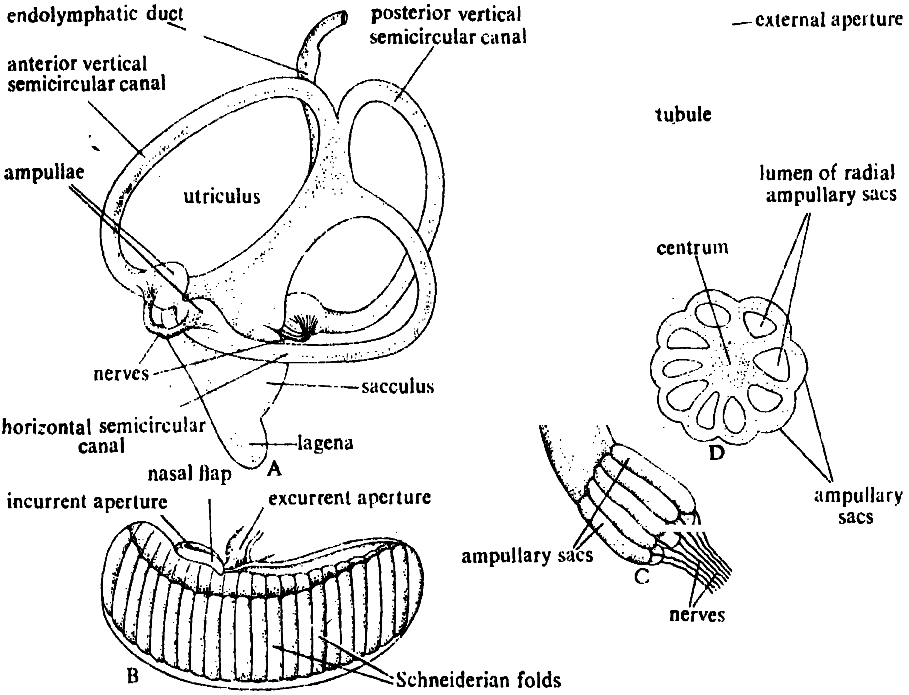

endolymphatic duct
posterior vertical semicircular canal
anterior vertical semicircular canal
ampullae
utriculus
nerves
sacculus
horizontal semicircular canal
lagena
A
external aperture
tubule
lumen of radial ampullary sacs
centrum
D
ampullary sacs
ampullary sacs
C
nerves
nasal flap
incurrent aperture
excurrent aperture
B
Schneiderian folds

Fig. 5.14. Sense organs of *Scoliodon*. A. Internal ear. B. Olfactory sac (dissected to show the inner nasal flaps). C. An ampulla of Lorenzini. D. Sectional view of an ampullary sac.

AUTONOMOUS NERVOUS SYSTEM

This system is made up of a series of paired ganglia arranged irregularly on the dorsal wall of the kidney and the posterior cardinal sinuses. The gastric ganglion is the largest ganglion and sends nerves to the viscera. There is usually one ganglion in each segment. In Scoliodon the successive ganglia have no distinct continuous chain.

SENSE ORGANS

The nervous system is associated with highly developed sense organs, viz. eyes, nose, ear and many others (Fig. 5.14).

EYES. The eyes are built on the principle of a photographic camera. The eye-ball is composed of three layers, the *sclera, choroid* and *retina*. The *sclera* is cartilaginous. The *pupil* is a vertical slit and can not be dilated or contracted. The retinal layer lacks the cones and is composed exclusively of rods. A large number of guanine plates is present on the inner surface of the choroid layer which is called the ***tapetum lucidum***. It acts as the reflector. The crystalline lens is spherical. The eyes are placed in the orbit and are kept in position by six muscles (Fig. 5.15) arranged in two groups and a cartilaginous ***optic stalk***.

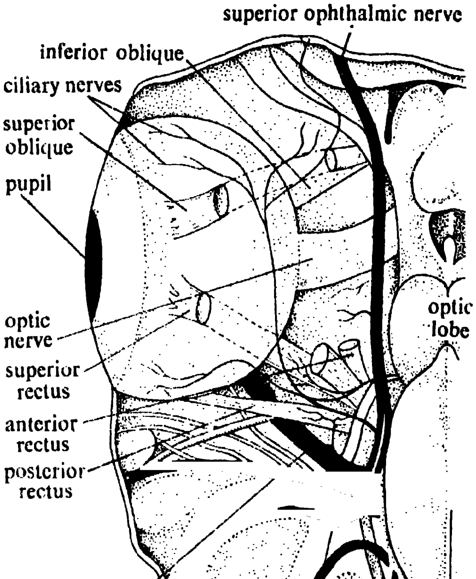


Fig. 5.15. Orbit of *Scoliodon*. Note the relationship of the eye with the brain, muscles, nerves (after Young.)

The eyes of Scoliodon are quite prominent and are proportionately larger in size. Eyes are laterally placed and each has its own range of vision, i.e., Scoliodon has monocular vision. Scoliodon is colour blind.

OLFACTORY ORGANS. There are two blind sac-like olfactory organs situated in front of the mouth. Each olfactory sac is placed in a cartilaginous capsule and does not communicate with the buccal cavity. The mucous membrane of the olfactory sac is thrown into two series of folds called the ***Schneiderian folds*** which are placed by the ***median raphe*** (See Fig. 5.14B). The Schneiderian folds are composed of ***olfactory sense cells*** and ***supporting cells***. The olfactory sense organs are greatly developed in Scoliodon. Physiologically each nasal opening is divided by three muscular nasal valves into a median ***excurrent siphon*** and a lateral ***incurrent siphon***.

INTERNAL EAR. The internal ear or the membranous labyrinth of Scoliodon is a closed ectodermal sac. It consists of three semicircular canals and a central body differentiated into an anterior ***utriculus*** and a ventral ***sacculus*** (See Fig. 5.14A). The three semicircular canals are arranged in three planes of the body and open into the central body by both ends. But one end of each canal dilates to form ***ampulla***. The utriculus gives off an invagination called the ***recessus utriculi*** beneath the ampullae of the anterior vertical and horizontal semicircular canals. The sacculus gives a posterior outgrowth called the ***lagena***. The membranous labyrinth is placed in a cartilaginous auditory capsule. The inner cavity is filled with a fluid called the ***endolymph*** into which many calcareous bodies (***otoliths***) are present. The space between the membranous labyrinth and the auditory capsule is filled with the ***perilymph***. A long tube called the ***endolymphatic duct*** communicates the cavity of sacculus to the exterior through a small opening. The membranous labyrinth of Scoliodon performs three functions: (1) It helps in orientation in relation to gravity, (2) it accelerates in changing the direction during swimming and (3) it helps in hearing. The utriculus together with the semicircular canals are responsible for the orientation and acceleration, while the sacculus is meant for hearing.

NEUROMAST ORGANS. These organs comprise of (*i*) the ***lateral line receptors*** and (*ii*) ***pit organs***. The lateral line sense organs lie inside the lateral line canal. These sense organs are epidermal derivatives and are called the *neuromasts* which remain embedded in the wall of the lateral line canal. This canal communicates to the exterior by minute pores. The pit organs occur on the lateral and dorsal sides of the head. They are ectodermal pits connected by groups of sense cells. The neuromast organs help to orient the body in relation to currents and waves and are designated as the *rheoreceptors*.

AMPULLAE OF LORENZINI. Enumerable pores on the dorsal and the ventral sides of the head lead into a long tube which terminates into radially arranged ampullary sacs (See Fig. 5.14C). The *ampullae* lie in clusters and each of these consists of eight or nine chambers arranged radially around a central core called the *centrum* (See Fig. 5.14D). Two types of cells are encountered in the ampullae—glandular cells and the sensory cells. The ampullae get the names according to their location. These sense organs are the thermoreceptors and are also the pressure receptors.

URINOGENITAL SYSTEM

The excretory organ consists of a pair of elongated *kidneys*. The functional adult kidneys are called the *opisthonephros* type according to Graham Kerr. The anterior portion of the kidney is nonfunctional and the posterior portion becomes greatly developed. The kidneys are composed of coiled glandular uriniferous tubules or *nephrons*. Each tubule consists of a double-walled cup (or Bowman's capsule) enclosing *glomerulus* and a much coiled renal tubule. A few renal tubules open into a common collecting tubule. The kidney tubules have the peculiar property of reabsorbing the urea. The collecting tubules of the anterior nonrenal portion of the kidney open to the Wolffian duct and the posterior tubules open into the ureter which in turn opens into the urinogenital sinus. The mesonephric duct divides into two. The dorsal one is named as the Wolffian duct and the ventral one is the Mullerian duct. The Wolffian duct in male, becomes the vas deferens which is connected with the vasa efferentia from the testis. The Mullerian duct becomes the oviduct in female.

The kidneys are extremely elongated structures extending from the root of the liver to the cloacal region. The posterior portion is designated as the kidney proper and becomes greatly developed. The anterior portion becomes narrower and takes part in conveying the genital products. This part is designated as the *organ of Leydig* or *epididymis*.

Male reproductive system. The *testes* are paired elongated organs (Fig. 5.16A). Each testis is attached to the dorsal body wall by peritoneal membrane called the *mesorchium* and posteriorly attached by ordinary tissue with the caecal gland. The sperm cells escape by *vasa efferentia* into the *vas deferens* which becomes extremely coiled in the anterior portion of the kidney. Posteriorly the vas deferens becomes very much dilated to form the *seminal vesicle*. The seminal vesicles open into the urinogenital sinus which in turn opens into the cloaca. The wall of the urinogenital sinus becomes evaginated to form a *sperm sac*. A pair of sacs designated as the *siphons* is present. The siphons are located under the skin on the ventral aspect of the body. Posterior to the sacs these are continued as the *siphon-tubes* which open to the groove of the clasper of the respective sides (Fig. 5.16C). The siphons are not connected with the genital system. They contain sea water and help in the expulsion of the sperms through the clasper-grooves.

Female reproductive system. In female there is no connection between the kidneys and the genital organs. Kidneys are typical excepting that the ureters unite posteriorly and open by a single urinary aperture into the urinary sinus.

Ovaries are two in number and are kept in position by peritoneal folds called the *mesovarium*. The shape, size and colour of the ovaries vary greatly according to the age of the individual. A pair of *epigonial organs* is present between the ovary and the rectal gland. The *oviducts* are very long tubes and are united both posteriorly and anteriorly (Fig. 5.16D). Posteriorly, two oviducts unite to form the *vagina* which opens into the *cloaca*. Anteriorly the oviducts converge and open into the coelomic cavity by a longitudinal slit-like opening designated as the *oviducal funnel*. At the anterior portion of each oviduct there is a dilated *shell gland* which has but little significance in Scoliodon. As Scoliodon is viviparous the posterior portion of the oviduct becomes dilated to form the *uterus* for the development of the young. The number of embryos present inside one uterus varies

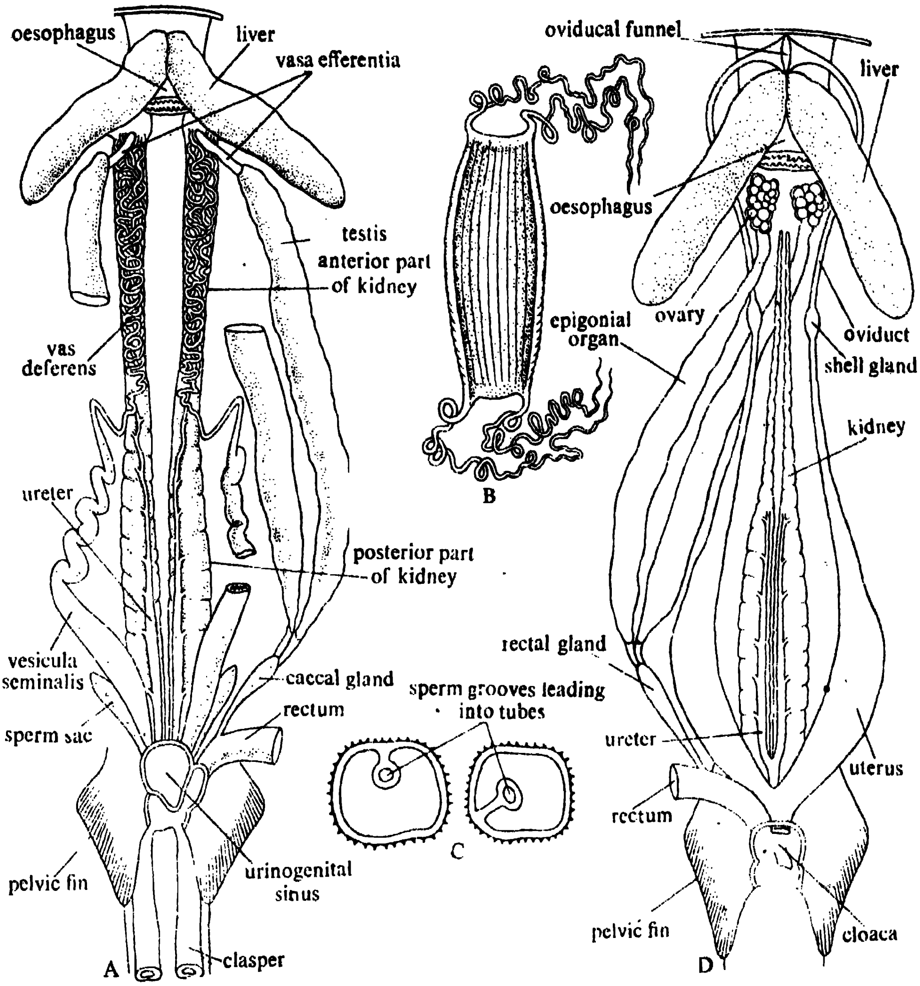

oesophagus
liver
vasa efferentia
testis
anterior part of kidney
vas deferens
ureter
posterior part of kidney
vesicula seminalis
caecal gland
rectum
sperm sac
urinogenital sinus
pelvic fin
clasper
A
B
C
sperm grooves leading into tubes
oviducal funnel
liver
oesophagus
epigonial organ
ovary
oviduct
shell gland
kidney
rectal gland
ureter
rectum
uterus
pelvic fin
cloaca
D

Fig. 5.16. Reproductive system of dog fish. A. Male reproductive system of *Scoliodon*. B. Egg capsule of *Scyliorhinus*. C. Sectional view of the claspers of *Scoliodon*. D. Female reproductive system of *Scoliodon*.

greatly in different species of *Scoliodon*. In *S. sarrakowah* about seven embryos have been observed. The mucous membrane of the uterus becomes divided into a number of compartments each of which houses an embryo. The number of compartment varies directly with the number of embryos.

The eggs are large and heavily yolked. Each egg gets a coating of albumen during its transit down the oviduct. The egg, particularly in oviparous forms, is enclosed by horny shell which is oblong in shape. The angles of the shell are prolonged into four coiled elongated filamentous processes (Fig. 5.16B). This condition is not observed in Scoliodon but is observed in case of oviparous sharks.

DEVELOPMENT

Scoliodon is viviparous and gives birth to living youngs. Fertilization is internal. It is claimed that during copulation the claspers are introduced into the cloacal aperture of the female for the transmission of spermatozoa. The egg of Scoliodon is strongly telolecithal. The cleavage is restricted to a small germinal disc which floats on the top of the yolk mass (Fig. 5.17A). The cleavage is meroblastic and the first cleavage plane is simply a furrow in the surface of the germinal disc. The second cleavage occurs at right angle to the first one (Fig. 5.17B). After this stage, the cleavage plane is irregular. By this way of cleavage, a *blastodisc* is separated from a layer of *periblast cells*. The periblast cells from a syncitial layer over the yolk mass. A *blastocoel* is formed between the blastodisc and the central region of the periblast. With the expansion of the blastocoel the blastodisc becomes multilayered. The posterior region of the blastodisc grows faster than the other regions and is raised from the yolk mass to become a double-layered germ ring. This germ ring is raised posteriorly to form a blastopore (Fig. 5.17 D). At this stage an upper layer (*epiblast*) and a lower *hypoblast* is separated. The blastocoel lies between the ectoderm epiblast and the inner hypoblast (mesendoderm). The process of gastrulation actually starts with the formation of the dorsal lip of the blastopore. The endoderm is differentiated by cellular proliferation from the underside of the hypoblast. The mesoderm produces a *prechordal plate.*

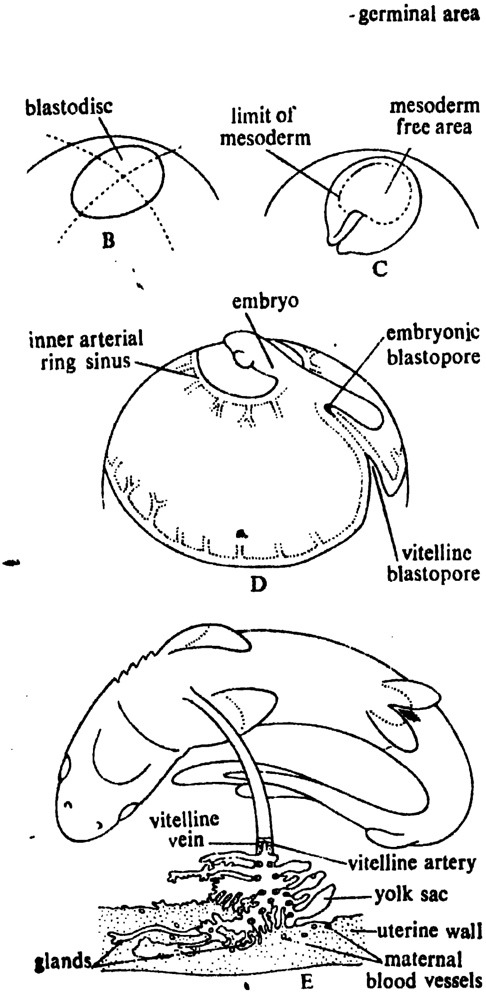


Fig. 5.17. Development of *Scoliodon*. A. First cleavage plane. B. Starting of gastrulation. C. Early neurula stage. D. Tail bud stage. E. Yolk sac placenta. Note the developing young gets the nourishment from the maternal blood (after Jollie).

As the embryo elongates along the anteroposterior axis, a *head fold* is marked off from the blastodisc and becomes raised up to form the neural folds. The body of the embryo is constricted from the blastodisc and the *tail fold* is differentiated and extended backward. The blastopore is separated into two (embryonic and vitelline blastopores) by the fusion of the edges of the yolk sac. The circulatory system appears in the mesoderm in the form of blood islets which unite to form vascular networks. As the embryo grows, the mouth is formed from the stomodaeal invagination and the anus is formed anew from the proctodaeal invagination because the embryonic blastopore becomes closed.

The developing embryo is provided with a tubular yolk stalk. This yolk stalk connects the intestine of the embryo with the yolk sac. The yolk sac contains yolk material which provides the nutrition for the developing embryo. When the yolk is fully exhausted the yolk sac becomes folded and becomes anchored with the uterine wall of the mother as the yolk-sac placenta. With the formation of placenta, the yolk stalk is lost and the blood vessels of the yolk stalk form the placental cord. The placental cord connects the embryo with the yolk-sac placenta (Fig. 5.17E). The placental cord develops many finger-like processes called the *appendicula*. The distribution of the appendicula in the placental cord varies in different regions. The appendicula help in the absorption of nutrients secreted from the uterine wall of the mother.

EXAMPLE OF BONY FISH—BHETKI

The Bhetki (*Lates calcarifer*) is one of the typical representatives of the bony fish. The anatomical construction of the animal will give an idea about the biology of the class Osteichthyes.

HABIT AND HABITAT

The Bhetki usually inhabits the saline estuaries, although occasional presence in fresh water streams is also observed. This fish is carnivorous and devours small fry of the fishes and crustacean larvae.

EXTERNAL STRUCTURES

The body of Bhetki is spindle-shaped and perfectly streamlined. The body is laterally compressed and modified in such a fashion as to facilitate swift movement in water (Fig. 5.18). The body is covered by dermal *scales* which are arranged in an imbricate fashion like the tiles on a roof. Overlying the scales there is a soft and thin epidermis which produces profuse quantity of mucus. The scales are of *ctenoid* type, i.e., the free posterior edge of the scale is provided with pointed outgrowths called the *ctenes*.

The body of Bhetki is distinctly divisible into *head*, *trunk* and *tail*. The head extends from the snout to the posterior end of *operculum;* the trunk covers the portion of the body from the posterior margin of the operculum and upto the anal opening; and the rest of the body behind the anal opening constitutes the post anal tail.

The head bears one pair of *eyes*. The eyes are situated one on each lateral side of the head. The eyes are lidless and are covered by a transparent protective membrane. A pair of *nostrils* is present in front of the eyes. The nostrils are peculiar, because these do not communicate with the buccal cavity. Consequently the nostrils have no respiratory role. The *mouth* is terminal in position and is comparatively wider. It is bounded with well-developed *jaws* bearing fine teeth. Besides the teeth on the jaws, there are also vomerine and palatine teeth. The teeth are very small in size. The *gill chamber* is covered by a bony gill-cover called the *operculum* on each side of the head. The operculum is supported by operculur bones. The free margin of the operculum is provided with a membranous flap called the *branchiostegal membrane*. The operculum and the branchiostegal membrane are movable structures. Each gill chamber contains four comb-like *gills*. The gill chamber opens to the exterior through an oblique slit behind the operculum. The slit can be tightly closed with the body by branchiostegal membrane. This slit acts as the exit for the respiratory water current.

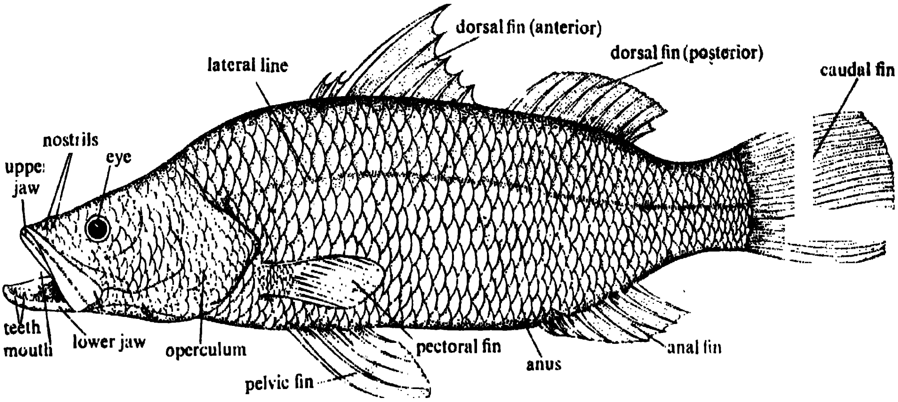


Fig. 5.18. External features of *Lates*.

A depression called the *vent* or *anus* is located on the ventral border of the body just at the junction of the tail and the trunk. The vent gets the opening of the *rectum* in front, an *urinary opening* behind and two *gonopores* at the two sides. Extending from the back of the operculum and upto the tail region there is a darker line on the lateral side of the body. This line is called the *lateral line*. The tail is supported by special muscles and acts as an efficient oar for propelling in water.

FINS

The appendages of this fish are called the fins. The fins are the membranous integumentary extensions of the body supported by fin-rays. The fins help in steering, balancing and checking of speed during movement in water. Fins can be distinguished as (A) the unpaired fins and (B) the paired fins.

Unpaired fins. The unpaired fins are median in position. These are: (1) *dorsal fins*, (2) *caudal fin* and (3) *ventral* or *anal fin*. The dorsal fins are situated on the middorsal side of the body and are differentiated into an anterior and a posterior part. The anterior part is supported by seven spinous rays; of which the third one is the longest. The posterior dorsal fin contains twelve rays, of which the first ray is spinous and the rest are soft. The caudal fin as the name suggests, is situated at the tip of the tail and is fan-shaped. It is supported by ten to twenty rays. The ventral or anal fin is located at the ventral border of the tail near the vent and is supported by twelve fin rays. Of these twelve fin rays, the first three are spinous and the rest are soft.

Paired fins. The paired fins are located on the lateral side of the body and are homologous with the limbs of higher vertebrates. The paired fins are: (1) *Pectoral fins*, situated one on each side of the body behind the operculum. Each pectoral fin is provided with fourteen bony fin rays. (2) *Pelvic fins* are located on the ventral side of body below and posterior to the pectoral fins. Each pelvic fin bears five rays, of which the front one is a spinous rod and the rest are bony rays.

MUSCULAR SYSTEM

The tail and the trunk are provided with well-developed V-shaped muscular blocks called the *myotomes* which help the fish to swim in water.

SKELETAL STRUCTURES

The scales and the fin rays constitute the exoskeletal structures of the body. The endoskeleton is mostly bony and consists of the axial and appendicular portions.

Axial skeleton. The axial skeleton is composed of the skull and the vertebral column. The skull is a very complicated anatomical structure. It consists of the *cranium*, the paired *sense capsules*, the *jaws*, the *hyoid* and *branchial arches*. The skull is immovably fixed with the vertebral column. The roof of the skull is composed of *frontals* and *parietals*. The posterior portion of the skull is made up of a *basioccipital* with single *occipital condyle*, a *supraoccipital* and two *exoccipitals* situated on the lateral side of the *foramen magnum*. A small Y-shaped *basisphenoid* is present in front of the basioccipital. A big *alisphenoid* is present on each side of the basisphenoid. A pair of bones called *orbitosphenoids* is also present in front of basioccipital.

A ring of scale-like bones surrounds the orbits that house the eyes. The anterior part of the orbit is called the *lacrymal*. The roof of the *nasal capsule* is formed of *nasals* which overlap the *ethmoid* bone and the floor is made up of *vomers*. The *otic capsule* is composed of *epiotic*, *prootic*, *pterotic* and *sphenotic* bones. The otic capsule accommodates the ear.

Jaws. The upper jaw consists of two series of bones. The outer series is formed of the membranous bones and the inner series is made of cartilaginous bones. The outer series is composed of *premaxilla*, *maxilla* with teeth and *jugal* on each side. The jugal is attached to the posterior side of the maxilla. The inner series is composed of a tooth-bearing *palatine*, a *pterygoid* and a *quadrate* articulating with the lower jaw. The lower jaw is made up of *Meckel's cartilage.* Three membranous bones, a tooth-bearing *dentary*, an *articular* articulating with the quadrate and a small *angular* surround the Meckel's cartilage.

Visceral arches. The visceral arches consist of seven pairs of rod-like structures. The arches remain cartilaginous in early life and become subsequently ossified. These support the jaws, tongue and the gills. The first arch is called the *mandibular arch* which is composed of two portions on each side, the *palatoquadrate* forming the inner series of the upper jaw and the *Meckel's cartilage* that forms the lower jaw. The second arch is called the *hyoid arch* that supports the tongue and the operculum. Each arch is composed of an anteriorly placed *hyomandibular* and a posterior *symplectic* bone. Several cartilaginous pieces lie ventral to hyomandibular and the symplectic bones. These are: *epihyal*, *interhyal*, *ceratohyal* and *basihyal*. These bones support the tongue and the floor of buccopharynx. Certain bones supporting the operculum and branchiostegal membrane become secondarily connected with the hyoid arch. The rest of the visceral arches are the *branchial arches* which support the gills. The last branchial arch is devoid of gill.

Vertebral column. The vertebral column is composed of a large number of *vertebrae* (Fig. 5.19). The vertebrae are of *amphicoelous* type, i.e., the centrum is concave on both the ends. The vertebrae can be differentiated broadly into the precaudal and the caudal types.

Structure of a typical precaudal vertebra. A typical precaudal vertebra bears a spool-like amphicoelous centrum. A narrow

neural spine is present on the dorsal side of the ***neural arch***. Paired ***transverse processes*** and paired ***pre-*** and ***postzygapophyses*** are present (Fig. 5.19A). There are downwardly curved ribs which remain articulated to the terminal end of the transverse processes.

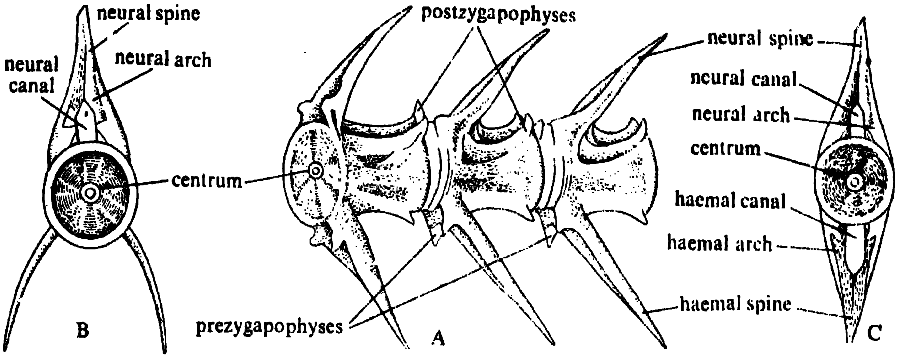

neural spine
neural arch
neural canal
centrum
B
postzygapophyses
prezygapophyses
A
neural spine
neural canal
neural arch
centrum
haemal canal
haemal arch
haemal spine
C

Fig. 5.19. Vertebrae of *Lates*. A. Showing three caudal vertebrae in their natural position. B. A precaudal vertebra. C. A caudal vertebra.

Structure of a typical caudal vertebra. Besides the structures present in the precaudal vertebra, the centum has a ventrally located *haemal arch* with a narrow *haemal spine* (Fig. 5.19C). The neural arch and the neural spine are present. The ribs are absent in the caudal vertebrae.

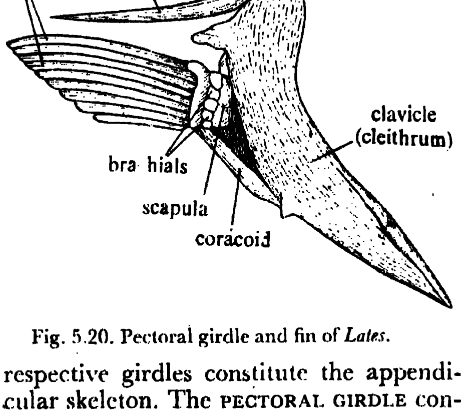

posttemporal
supraclavicle
finrays
postclavicle
clavicle
(cleithrum)
bra hials
scapula
coracoid

Fig. 5.20. Pectoral girdle and fin of *Lates*.

Appendicular skeleton. The skeletal elements supporting the paired fins and the respective girdles constitute the appendicular skeleton. The PECTORAL GIRDLE consists of a few bones which support the pectoral fins on either side. Each half of the pectoral girdle is composed of (*i*) a dorsally placed ***scapula***, (*ii*) a ventrally located ***coracoid*** and (*iii*) a large ***cleithrum*** or ***clavicle*** articulating with the coracoid. The dorsal end of the clavicle is produced into a backwardly extended *postclavicle* and an upwardly directed stout *supraclavicle* (Fig. 5.20). The supraclavicle is connected with the skull by a forked *posttemporal* bone. The clavicles, one from each half of the pectoral girdle, are joined at the midventral line of the body.

Four or five *pterygiophores* or ***brachial*** *ossicles* supporting the *dermotrichia* or ***fin rays*** of the pectoral fin are attached to the scapula and coracoid on their posterior edges. The skeleton composing the PELVIC GIRDLE is very simple and is represented by a thin plate-like *basipterygium* on each side. It gives support to the dermotrichia of the pelvic fin.

COELOM

The coelom is spacious and is divided into an anterior *pericardial cavity* containing the heart and a posterior large *perivisceral cavity* to accommodate the digestive organs, swim bladder, urinogenital organs and other visceral organs (Fig. 5.21).

DIGESTIVE SYSTEM

The digestive system of Bhetki consists of the alimentary canal and the digestive glands. The alimentary canal starts with the mouth and terminates in the anal opening. The mouth is a very wide slit and is bounded by upper and lower jaws. The jaws are beset with numerous sharp conical teeth. The mouth opens into the spacious buccal cavity. A small and non-

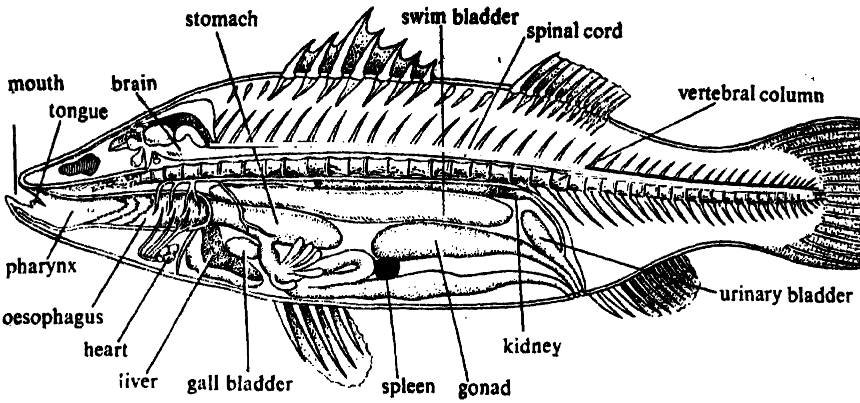

stomach
swim bladder
spinal cord
mouth
brain
tongue
vertebral column
pharynx
urinary bladder
oesophagus
heart
kidney
liver
gall bladder
spleen
gonad

Fig. 5.21. Diagrammatic longitudinal sectional view of *Lates* showing the position of the major visceral organs

muscular tongue is attached to the floor of the buccal cavity. Salivary glands are absent. There are numerous mucous glands which pour their secretion into the *buccal cavity*. The buccal cavity is continued as the *pharynx*. The pharynx is spacious and is supported by the branchial or gill arches on the lateral side. Five gill slits situated between the gill arches communicate the pharyngeal cavity with the gill chamber. The gill rakers present on the concave side of the gill arches prevent the escape of food materials from the pharyngeal cavity into the gill chamber. The pharynx leads into a short tubular *oesophagus*. The oesophagus leads into the *stomach* and the opening to the stomach is guided by sphincter muscle to prevent the entry of water into the stomach. The stomach is nearly a V-shaped sac and is generally divided into *cardiac* part towards the oesophageal side and the *pyloric* part to the opposite end which is continued into the *intestine*. This point is provided with a well-marked *pyloric constriction*. The intestine is fairly long. Five blind finger-like structures called the *pyloric caeca* are present in the intestine very close to the pyloric stomach (Fig. 5.22). The function of these structures is not definitely known. These are either secretory in function or help in the absorption of the digested food. The intestine forms a loop and opens at the anus. The mesentery which supports the gut is heavily loaded with fat.

Digestive glands. The *liver* constitutes the major digestive gland. It is a massive structure and consists of two lateral lobes connected by median transverse part. It is located in the anterior part of the perivisceral cavity. The products of the liver, the bile

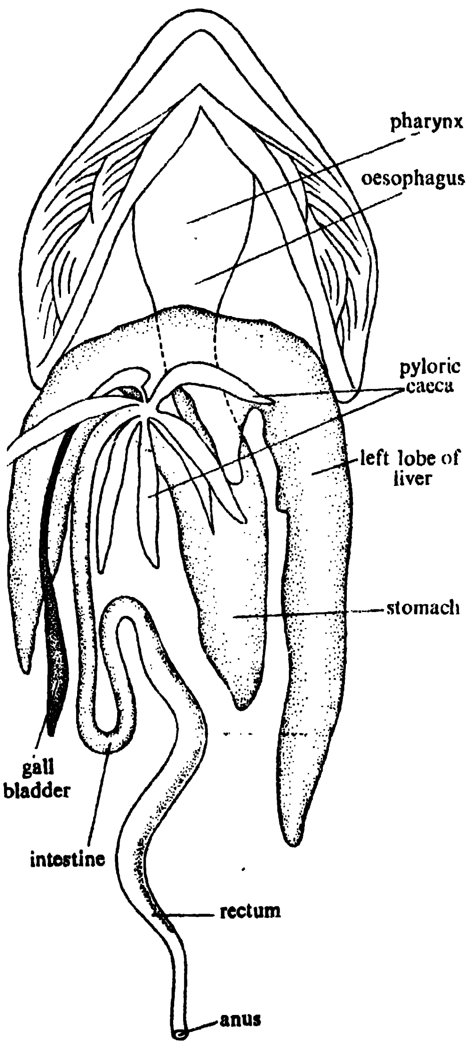

pharynx
oesophagus
pyloric caeca
left lobe of liver
stomach
gall bladder
intestine
rectum
anus

Fig. 5.22. Digestive system of *Lates*.

is stored in a thin-walled *gall bladder*. The gall bladder is composed of two unequal sacs which are connected by a narrow tube. One of the lobes is located at the tip of right part of liver and the other is located at the median part. The bile is poured into the intestine by the bile duct. There is no separate existence of *pancreas*. Diffused occurrence of pancreatic cells in the substance of liver is recorded. So the bile poured into the intestine also contains the pancreatic secretion.

HYDROSTATIC ORGAN

Just below the vertebral column in the dorsal side of the perivisceral cavity there lies a large SWIM BLADDER. It develops as an outgrowth from the anterior part of the digestive tube and leaves a narrow tubular connection with it called the *ductus pneumaticus*. This connection becomes lost in adult. So this type of swim bladder is called the *physoclistous* type. The swim bladder is filled with gases and consists of two unequal chambers. The anterior chamber is smaller and the posterior one is elongated. The inner lining of the swim bladder is highly vascularised which thus forms the *rete mirabile*. The rete mirabile present in the anterior chamber has an extraordinary power of isolating molecules of oxygen, carbon dioxide, nitrogen from the blood and filled in the said chamber with these secreted gases. But the rete mirabile in the posterior chamber subserves the reverse role, i.e., it can reabsorb the gases. The swim bladder is a very important structure and plays a number of vital functions. It acts primarily as the hydrostatic organ. By alternate production and reabsorption of the gases inside the chambers of the swim bladder, the fish can regulate the specific gravity of the body in water.

RESPIRATORY SYSTEM

The respiration is performed by four pairs of *gills*, situated in the *gill chambers*. These two chambers are covered externally by the *operculum* and the *branchiostegal membrane* which is attached to the posterior margin of the operculum. The wall of pharynx is perforated by five *gill slits* on each side and are separated by four *gill arches* or *interbranchial septa*. Each gill arch is provided with teeth-like *gill rakers* on the inner concave border and two rows of comb-like *gill filaments* on the outer convex border (Fig. 5.23). The gill rakers present in the inner borders of the gills, prevent the escape of food materials from the pharyngeal cavity to the gill chamber. The gills are *holobranchs*, i.e., each gill arch bears two rows of gill filaments.

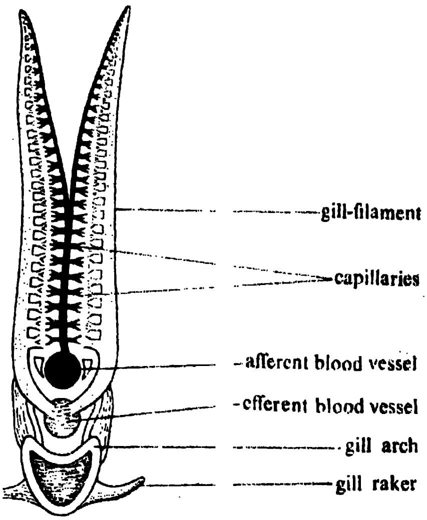


Fig. 5.23. Diagrammatic sectional view of a gill of *Lates*.

PHYSIOLOGY OF RESPIRATION. Bhetki utilises the oxygen dissolved in water. The physical mechanism of respiration can be described under two sequences (Fig. 5.24). *Inspiration.* During inspiration, the outer opening of the gill chamber remains tightly closed to the body wall by the branchiostegal membrane and the two opercula bulge out to increase the accommodating capacity of the pharyngeal and buccal cavity. As a consequence, water from exterior rushes inside through the opened mouth and fill in the buccopharyngeal cavity. *Expiration.* Immediately with the entry of water, the pharyngeal and the buccal cavity contracts and exerts pressure to the contained water. As the mouth, by this time, becomes closed by oral valves, the contained water finds the way out through the gill slits. The operculum as well as the branchiostegal membrane are lifted by this time and the water from the gill chambers goes out through the opening of the gill chamber. The dilatation and the contraction of the pharyngeal cavity are caused by the alternate retraction and protraction of the hyoid arch supporting the buccopharyngeal cavity.

PHYSIOLOGY OF GASEOUS EXCHANGE. The gills are highly vascular structures and are supplied by afferent and efferent branchial arteries. The afferent branchial artery carrying the deoxygenated blood is situated very superficially on the outer edge of the gill. The afferent branchial artery breaks up into capillaries in the substance of the gill. During the transit of water through the gill slits, the deoxygenated blood in the capillaries of the gill filaments takes oxygen dissolved in water and gives out carbon dioxide by diffusion. The blood thus aerated, is collected by efferent branchial arteries and is conveyed to the different parts of the body.

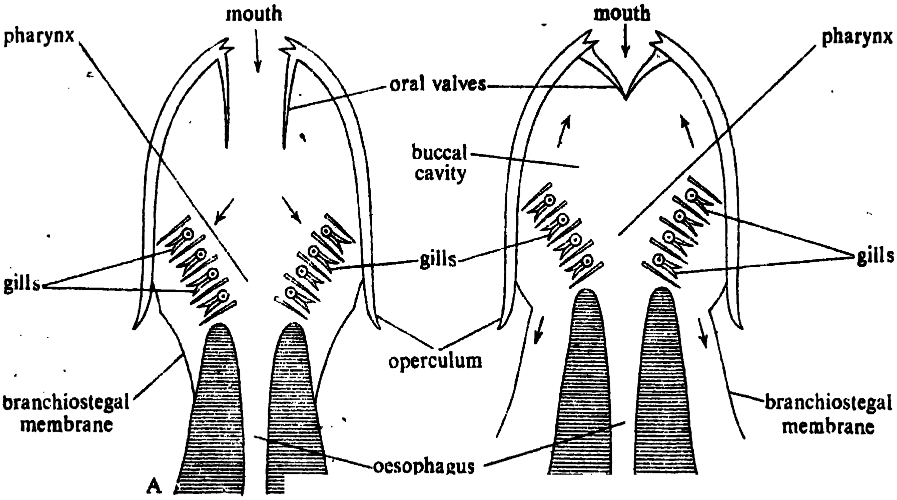

mouth
pharynx
oral valves
buccal cavity
gills
gills
operculum
branchiostegal membrane
oesophagus
A
mouth
pharynx
gills
branchiostegal membrane

Fig. 5.24. Schematic diagrams showing the physical mechanism of respiration in *Lates*. A. Inspiration. B. Expiration. The arrows indicate the direction of respiratory water current.

CIRCULATORY SYSTEM

The circulatory system of Bhetki comprises of (1) the circulatory fluid—the blood, (2) the pumping organ—the heart, (3) the arteries and (4) the veins.

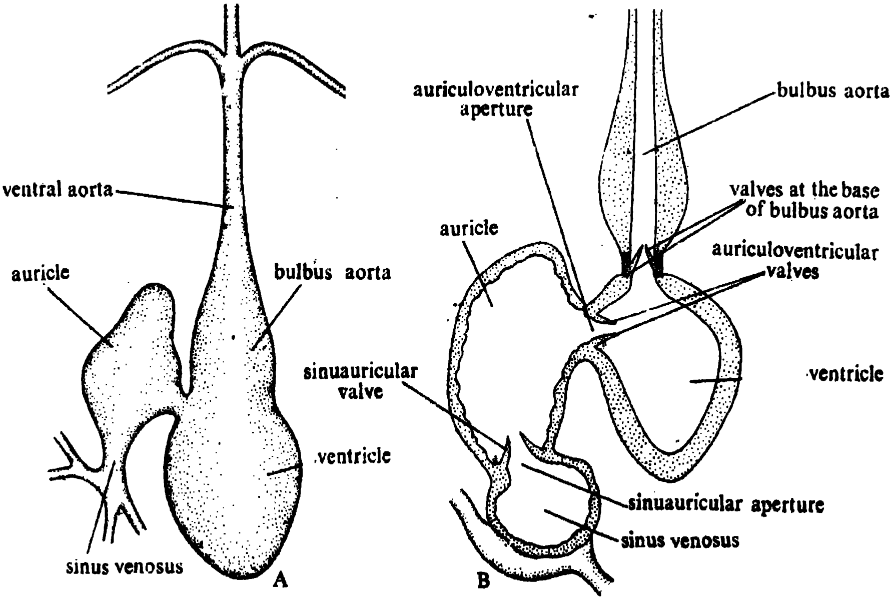

ventral aorta
auricle
bulbus aorta
sinuauricular valve
ventricle
sinus venosus
A
auriculoventricular aperture
bulbus aorta
valves at the base of bulbus aorta
auricle
auriculoventricular valves
ventricle
sinuauricular aperture
sinus venosus
B

Fig. 5.25. Heart of *Lates*. A. Intact heart. B. Sectional view of heart through the different chambers. Note that the conus arteriosus is represented by a pair of valves guarding the opening of the bulbus aorta.

BLOOD. Blood is a pale coloured fluid. It contains elliptical, nucleated erythrocytes and amoeboid leucocytes suspended in the plasma.

HEART. The heart is located ventral to the oesophagus in the pericardial section of the coelom. It is enclosed within a thin pericardium. It is constructed of two types of chambers:

Receiving chambers. The *sinus venosus* and the *auricle* constitute the receiving parts of the heart. The sinus venosus is a dorsally placed thin-walled sac. It receives deoxygenated blood by two *caval veins* or *ductus Cuvieri.* The auricle is a single thin-walled chamber and is situated ventral to the sinus venosus. The sinus venosus opens to the auricle by a *sinuauricular aperture* guarded by valves (Fig. 5.25B). The auricle opens into the ventricle by *auriculoventricular aperture.* This aperture is guarded by valves. Through both these aforesaid apertures the blood flows in the direction from sinus venosus to auricle and from auricle to the ventricle respectively. The valves guarding the apertures prevent the change of direction or back-flow of blood and thus maintain a unidirectional flow of blood through the different parts of the heart.

Forwarding chamber. The forwarding chamber of the heart is exclusively the thick-walled conical *ventricle.* It is placed ventral to the auricle. There is no conus arteriosus. This part of the heart is represented by a pair of valves guarding the entrance of the bulbus aorta. The bulbus aorta is a dilated part at the base of the ventral aorta and is not to be regarded as the component part of the heart.

ARTERIAL SYSTEM

The arterial system of the Bhetki consists of two categories of arteries depending on the type of blood the vessels carry. The afferent branchial arteries carry the deoxygenated blood from the heart to the gills and the efferent branchial arteries collect oxygenated blood from the gills and convey the same to the different parts of the body.

Afferent Branchial System. From the base of the ventricle arises a very stout median artery called the *ventral aorta.* The base of the ventral aorta becomes dilated to form a noncontractile *bulbus aorta.* The ventral aorta proceeds forward along the floor of pharynx and occupies a midventral position. From the ventral aorta the paired *afferent branchial arteries* emerge out to supply the gills (Fig. 5.26). The afferent branchial arteries carry the deoxygenated blood from the heart to the gills for aeration. The ventral aorta bifurcates anteriorly to form the first pair of afferent branchial arteries which goes to the first pair of gills. The second pair of afferent branchial arteries originates behind the first pair and enters the second pair of gills. The third and fourth pairs of afferent branchial arteries have a common origin and arise from the posterior part of the ventral aorta, i.e., the third and fourth afferent branchial arteries have a common root. Thus the ventral aorta and the afferent branchial arteries carrying deoxygenated blood to the gills constitute the afferent branchial system.

Efferent Branchial system. One of the peculiar features in the circulatory system of fish is that the oxygenated blood from the gills is not returned to the heart but is carried directly to the different parts of the body through the *efferent branchial arteries* which constitute the efferent branchial system (Fig. 5.27). The heart is called the venous heart, because only deoxygenated blood circulates through the different parts of the heart. There is no provision for separation of deoxygenated and oxygenated blood inside the heart as in higher forms. The efferent branchial system consists of four pairs of *efferent branchial arteries* corresponding to the number of gills. The first and second efferent branchial arteries on each side unite to form the *anterior epibranchial artery.* Two anterior epibranchial arteries unite posteriorly along the middorsal line to form the *dorsal aorta.* The third and fourth efferent branchial arteries on each side unite to form the *posterior epibranchial artery* which opens to the anteriormost end of the dorsal aorta. On each side, the first efferent branchial artery gives origin to a *cephalic artery* which in turn divides into an *external carotid artery* supplying blood to orbital region, tongue and hyoid arch and an *internal carotid artery* supplying blood to the brain. The dorsal aorta extends backward and lies ventral to the vertebral column. It terminates at the tail as the *caudal artery.* The dorsal aorta gives the following arteries anteroposteriorly: (1) A stout *coeliacomesenteric* artery originates from the anterior part of the dorsal aorta and supplies the swim bladder, stomach, intestine, liver, spleen, etc. (2) Just posterior to the coeliacomesenteric artery arises a pair of *subclavian arteries*. Each subclavian artery divides into two branches, the *pectoral artery* supplying the pectoral fin and the *pelvic artery* to the pelvic fin. (3) The rest of the dorsal aorta gives off a number of paired *segmental arteries* to the body musculature, *renal arteries* to the kidneys and the *genital arteries* to the gonads.

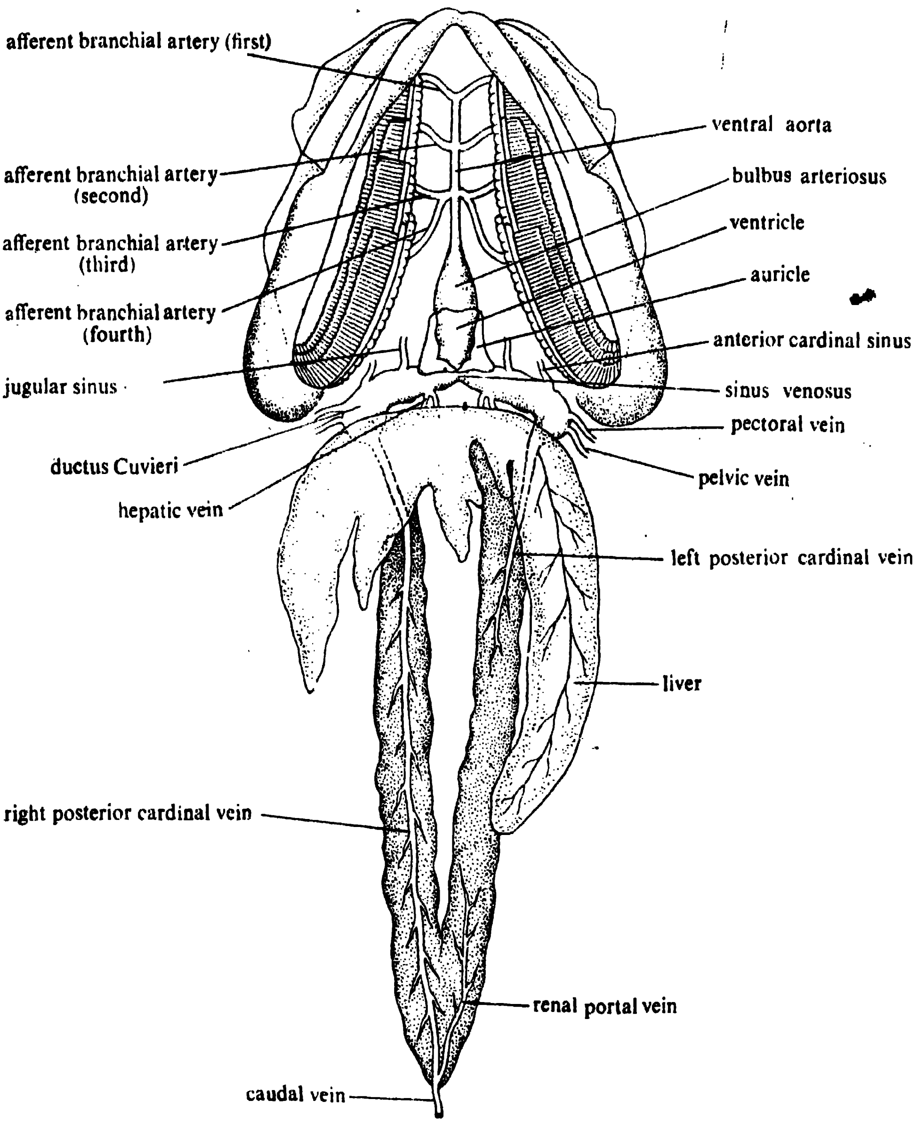

afferent branchial artery (first)
afferent branchial artery (second)
afferent branchial artery (third)
afferent branchial artery (fourth)
jugular sinus
ductus Cuvieri
hepatic vein
right posterior cardinal vein
caudal vein
ventral aorta
bulbus arteriosus
ventricle
auricle
anterior cardinal sinus
sinus venosus
pectoral vein
pelvic vein
left posterior cardinal vein
liver
renal portal vein

Fig. 5.26. Afferent branchial arteries and the principal veins of *Lates*.

VENOUS SYSTEM

The venous system of the Bhetki comprises of the *systemic veins* and the *portal veins*. These veins directly or indirectly convey the deoxygenated blood from the different parts of the body to the heart.

SYSTEMIC VENOUS SYSTEM. The blood is carried to the sinus venosus by right and left *ductus Cuvieri*. Each ductus Cuvieri is formed by three principal veins: an *anterior cardinal sinus*, a *jugular sinus* and a *posterior cardinal sinus*. The anterior cardinal sinus brings blood from the anterior part of the body (Fig. 5.26) and the posterior cardinal sinus brings blood from the posterior part of the body. Both the posterior cardinal veins receive segmental veins, renal veins, genital veins etc.

In addition to the above mentioned three principal veins, the *pectoral* and *pelvic* veins from the pectoral and pelvic fins respectively and the slender *hepatic* vein open into the *ductus Cuvieri*.

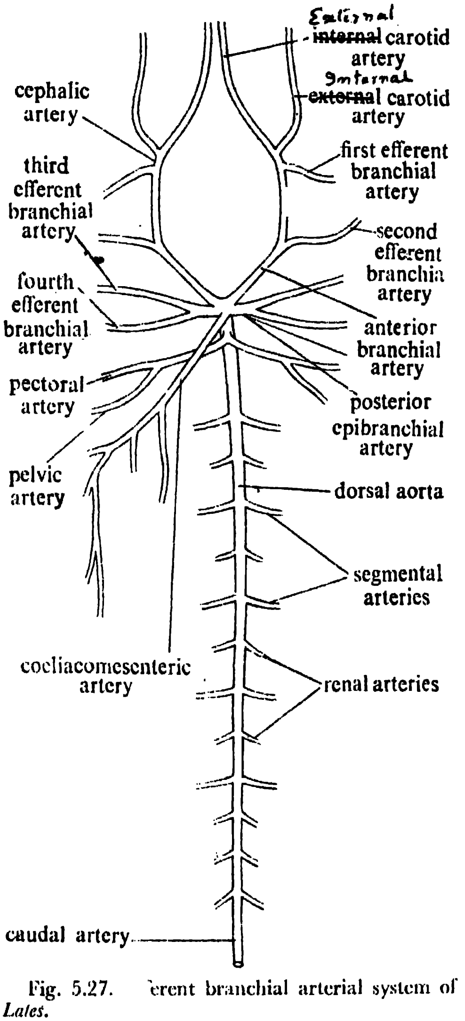

External
~~internal~~ carotid artery
Internal
~~external~~ carotid artery
cephalic artery
first efferent branchial artery
third efferent branchial artery
second efferent branchia artery
fourth efferent branchial artery
anterior branchial artery
pectoral artery
posterior epibranchial artery
pelvic artery
dorsal aorta
segmental arteries
coeliacomesenteric artery
renal arteries
caudal artery

Fig. 5.27. erent branchial arterial system of *Lates*.

The blood from the tail region is conveyed by a *caudal vein* which just entering into the trunk bifurcates into two branches. The right posterior cardinal sinus passes through the substance of the right kidney and opens into the right ductus Cuvieri. The left posterior cardinal vein originates from the capillaries of the renal portal vein.

PORTAL VENOUS SYSTEM. The portal venous system is composed of a special vein which originates in capillaries and end in capillaries and secondly the blood from these veins before going to the heart passes through some intermediate organs. When the intermediate organ is the kidney, such a system constitutes the *renal portal system* and when the organ is liver the system is called the *hepatic portal system*. *Renal portal system*. The left branch of the caudal vein after entering into the left kidney breaks up into capillaries and form the *renal portal vein*. These capillaries reunite and form the left posterior cardinal vein. *Hepatic portal system*. The capillaries from the alimentary canal and its associated structures unite to form a *hepatic portal vein* which enters into the substance of liver and breaks up into the capillaries. The capillaries reunite to form the hepatic vein which opens to the ductus Cuvieri.

NERVOUS SYSTEM

The nervous system of Bhetki comprises of the central nervous system, peripheral nervous system and the sympathetic nervous system.

CENTRAL NERVOUS SYSTEM. This system is composed of the brain and the spinal cord.

Brain. The brain consists of the *forebrain* or *prosencephalon*, the *midbrain* or *mesencephalon* and the *hindbrain* or *rhombencephalon*. The forebrain is again differentiated into an anterior *telencephalon* and a posterior *diencephalon* or *thalamencephalon*. The telencephalon gives rise to two well-developed *olfactory lobes* and two *cerebral hemispheres* (Fig. 5.28). The floor of the cerebral hemispheres is well-formed and is called the *corpus striatum*. The roof (or pallium) of the same is nonnervous in nature. The diencephalon is also ill-developed and is represented by a median diamond-shaped area between the optic lobes and the cerebral hemispheres. It is bounded dorsally by *epithalamus*, laterally by *thalami* and ventrally by *hypothalamus*. Projecting from the epithalamic region, there is a slender *epiphysis* with an insignificant *pineal body* attached to it. The floor gives out an *infundibulum* with the *pituitary body* attached to its anterior end. At the tip of the infundibulum there is a highly vascularised structure called the *saccus vasculosus* which secretes the cerebrospinal fluid. On either side of the pituitary body there are two *lobi inferiores*. The *optic chiasma* is wanting and the optic nerves of the optic lobes form a simple crossing. The midbrain constitutes the greater part of the brain and is represented by two round *optic lobes* dorsally and the *crura cerebri* on the ventral side. The hindbrain is differentiated into an anterior metencephalon and a posteriorly placed myelencephalon. The metencephalon is represented by a long and oblong shaped *cerebellum*. The myelencephalon gives rise to the *medulla oblongata* which is continued posteriorly into the spinal cord. The medulla oblongata is well-developed.

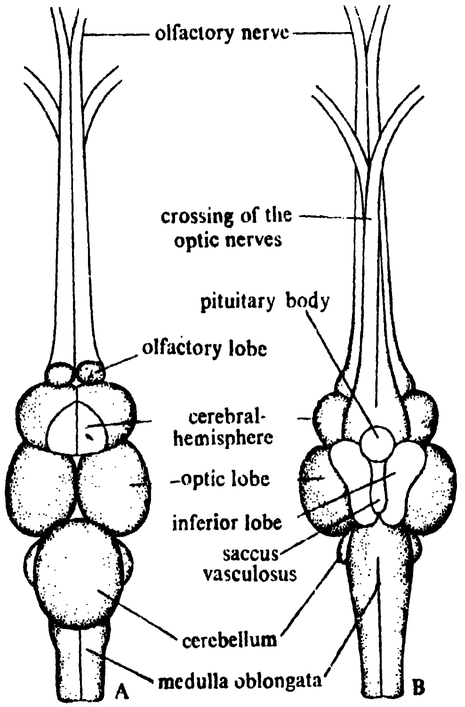


Fig. 5.28. Brain of *Lates*. A. Dorsal view. B. Ventral view.

PERIPHERAL NERVOUS SYSTEM. This nervous system comprises of the cranial, spinal and sympathetic nerves.

CRANIAL NERVES. There are ten pairs of cranial nerves. These are: (1) The first cranial nerve is the *olfactory nerve* supplying nerves to the olfactory capsules. (2) The second cranial nerve is the *optic nerve* supplying nerves to the eyes. The *optic nerves* cross one another without forming any chiasmata. (3) The third cranial nerve is the *oculomotor* supplying nerves to the extrinsic muscles of the eye-ball. (4) The fourth cranial nerve is the *trochlear* or *pathetic*. This nerve also supplies the extrinsic muscles of the eye-ball. (5) The fifth cranial nerve is the *trigeminal* which gives three main branches: (*a*) the *ophthalmic branch* which again bifurcates into a *superficial ophthalmic* and a *deep ophthalmic* branches, (*b*) a *maxillary* branch supplying the upper jaw and (*c*) a *mandibular* branch innervating the lower jaw. (6) The sixth cranial nerve is the *abducen* supplying the extrinsic muscles of the eye-ball. (7) The seventh cranial nerve is the *facial* nerve which gives two branches outside the skull, the *palatine* branch and a *hyomandibular* branch. Besides the branches, it has a *cutaneous* branch. (8) The eighth cranial nerve is the *auditory* nerve innervating the membranous labyrinth. (9) The ninth cranial nerve is the *glossopharyngeal* supplying nerves to the first gill-slit. (10) The tenth cranial nerve is the *vagus* which is divided into two: (*a*) the *lateralis* supplying nerves to the lateral line sense organ and (*b*) the *visceralis* innervating the second, third and fourth gill-slits. The nerve supplying the last gill-slit sends branches to heart, alimentary canal and swim bladder.

SPINAL NERVES. The spinal nerves are paired and supply nerves to the trunk and tail regions. Each spinal nerve, like that of Scoliodon, originates by a dorsal sensory root and a ventral motor root.

SYMPATHETIC NERVOUS SYSTEM. The sympathetic nervous system is more advanced than that of Scoliodon. The sympathetic nerve trunks are without any ganglion.

SENSE ORGANS

The main sense organs are the eyes, ears, olfactory organs, receptors for touch, receptors for taste and the lateral line sense organs.

EYES. The paired eyes are the photoreceptors. The eye-ball is three-layered. The outer or *sclerotic layer* contains cartilage, a median vascular *choroid layer* and an innermost photosensitive *retinal layer*. The choroid layer contains the choroid glands which surround the optic nerves. The eyes are devoid of eyelids. The cornea is flat. The lens is globular and lies in apposition to the cornea. The anterior chamber of the eye is greatly reduced. Between the choroid and the sclerotic layers there is a silvery reflecting layer or *argentea*. There is no ciliary muscle but there is a peculiar *falciform process* in the posterior chamber of the eye which helps in changing the position of the lens (Fig. 5.29A). The falciform process is the vascular fold of the choroid. This fold pierces the retinal layer near the entrance of the optic nerve and proceeds to the back of the lens. The back of the lens is attached to the falciform process by a *retractor lentis* muscle. Each eye has different visual field and the vision is thus monocular. Accommodation is effected by shifting the position of the lens and not by changing the shape of the lens as observed in higher vertebrates.

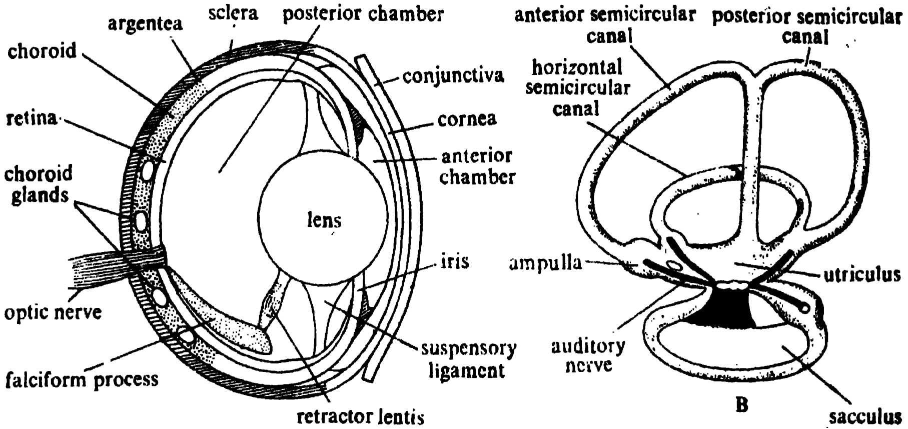


Fig. 5.29. Sense organs of *Lates*. A. Diagrammatic sectional view of an eye. B. An internal

EAR. The ear is exclusively composed of internal ear or *membranous labyrinth*. The middle and external ears of higher vertebrates are absent. The membranous labyrinth is composed of an upper chamber called *utriculus* and a lower *sacculus* (Fig. 5.29B). Three semicircular canals open into the utriculus. The sacculus is a sac-like structure whose floor gives rise to a *lagena*. The endolymph contains ear-stones or *otoliths* which touch the sensory hairs of both the chambers. The semicircular canals and the utriculus help the animal to maintain equilibrium. The sacculus and the lagena perceive the sound waves. As there is no tympanum, the body surface transmits the vibration to the inner ear. The lateral line sense organ helps the fish to perceive low frequency vibrations in water. The ears thus constitute the audio-equilibrating sense organs. Although the organ of Corti (the sensory area responsible for hearing in higher vertebrates) is lacking, this fish can undoubtedly hear.

OLFACTORY SENSE ORGAN. The olfactory sense organ is represented by two blind *nasal sacs*. The olfactory cells lining the nasal sacs are sensitive to smell. The nasal sacs do not communicate to the buccal cavity but open to the exterior by openings. The nasal sacs are exclusively olfactory in function and do not play any role in respiratory system.

SENSE ORGANS OF TOUCH. There is no such definite organ but the tactile cells on the lips and on the surface of the body serve the purpose.

SENSE ORGANS OF TASTE. Although tongue is present, it does not perform the said function. The cells in the mucous membrane of the mouth as well as on the whole body surface may serve the purpose.

LATERAL LINE SENSE ORGANS. The lateral line sense organs are well-developed in Bhetki. This lateral line system is composed of a large number of deep seated sense organs (Neuromasts). Each sense organ is housed in a pit and is communicated to the surrounding water by a pore. The lateral line sense organs are innervated by the lateral line branch of the vagus. This sensory system primarily helps the animal to perceive low frequency vibrations in water.

EXCRETORY SYSTEM

The excretory organ of Bhetki comprises of two elongated kidneys located ventral to the vertebral column and extending the whole of coelom. Kidneys are of mesonephric type. The two kidneys are fused partially at the posterior end. Each kidney is composed of numerous *uriniferous tubules*. On the ventral surface many minute apertures called the *nephrostomes* are present. These apertures communicate with the uriniferous tubules. The uriniferous tubules open to a tube called the *ureter* which emerges from the posterior part of the kidney. Two ureters from the two kidneys unite at the posterior end to form a common ureter which communicates with the *urinary bladder*. The bladder in turn opens to vent through a narrow duct. The urinary bladder in this fish is a mesodermal derivative and as such is not homologous to the endodermal bladder of higher vertebrates.

REPRODUCTIVE SYSTEM

The sexes are separate. The gonads exhibit seasonal variation and attain maximum size during breeding season.

Male Reproductive System. The testes are two in number and are elongated structures. Each testis is composed of seminiferous tubules and gives out a *vas deferens* which opens to the lateral side of the vent. There are two genital openings.

Female Reproductive System. The ovaries are much longer than the testes and contain numerous eggs. Matured eggs are conveyed through the oviducts and are discharged to exterior by reproductive openings. There are two genital openings located at the lateral sides of the vent.

DEVELOPMENT

The developmental events are not properly studied in this particular fish. The following description will give an idea of the process. The males discharge the seminal fluid on the freshly laid eggs. The eggs are protected by thick membrane (zona radiata) which prevents the eggs from mechanical injuries and microbial attack. The zona radiata is perforated by an aperture (*micropyle*). Through the micropyle a spermatozoon enters into the egg and fertilizes it. Fertilization is thus external.

Initially the egg is composed of a thin protoplasmic layer which envelops a mass of pale yellow yolk. Soon after fertilization the protoplasmic portions are accumulated at one end to form an elevated *germinal disc*. This disc becomes the seat of embryonic activity. The cleavage is restricted to the germinal disc. The cleavage is *meroblastic*. The segmentation cavity appears between the yolk and the blastoderm cells. In comparison to that of Scoliodon, the blastoderm is larger in size in this fish because of the smaller proportion of the yolk material. Consequently the size of the developing embryo is proportionately larger than that of the cartilaginous fishes. The developing embryo arises from the blastoderm and remains in close contact with the yolk for drawing the nutrition. As the embryo grows, the head and the tail ends become free from the yolk and the embryo hatches in this condition. The yolk sac remains still attached to the ventral surface of the embryo. With the availability of nutrition from outside, the yolk sac is lost and the embryo transforms into an independent fish. The development of nervous system is peculiar. It is formed as a solid keel-like ridge which becomes subsequently hollow to form a tubular nerve cord with the contained cavity, the neurocoel.

EXAMPLE OF BONY FISH—LATA

The lata fish (*Ophiocephalus* or *Channa punctatus*) is the commonest bony fish used in the practical classes in the different colleges of West Bengal and other provinces of India. These fishes are commonly called the snake-headed fishes because the head resembles superficially that of snakes. The anatomy of Lata is incompletely known. It is typically constructed on the teleostean plan. However, the following description will be helpful in the practical works.

HABIT AND HABITAT

The lata fish inhabits the fresh water ponds and ditches. It is usually carnivorous and eats other small fishes and other small aquatic animals. Lata fish is notable for migration overland from one pond to another during rains. The ability to breathe by its accessory respiratory organ helps the fish to thrive well out of water for a considerable period of time.

EXTERNAL STRUCTURES

The body of Lata is elongated (Fig. 5.30) and covered with *ctenoid* scales (Fig. 5.31B). It has

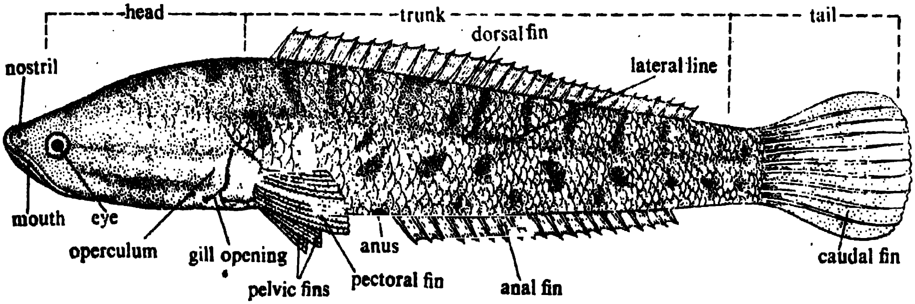


Fig. 5.30. External features of *Channa*.

been recorded that *cycloid* scales are also present (Fig. 5.31A). The body is divided into the *head*, *trunk* and *tail* regions. The head is depressed and covered by large plate-like scales resembling the 'head shields' of snakes. The eyes are placed on the lateral sides of the head. The dorsal fin is single.

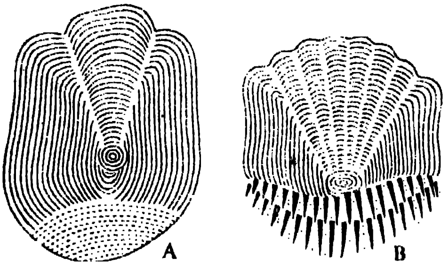


Fig. 5.31. Scales of fishes. (A) a typical cycloid scale. (B) a typical ctenoid scale.

The anal fin is also extensive and extends from the posterior end of the anus. Both the dorsal and anal fins are undivided and are supported by spinous bony fin-rays. The caudal fin resembles closely to that of Bhetki. The lateral line is interrupted at places.

DIGESTIVE SYSTEM

The mouth is bounded by upper and lower *jaws*. The jaws are provided with sharp conical *teeth*. The *buccal cavity* is spacious and leads into a short tubular *oesophagus*. The *stomach* is an elongated sac-like structure. The most important feature to note in the digestive system of Lata is the presence of only two *pyloric caeca* (Fig. 5.32). These caeca open at the junction of the intestine with the pyloric end of the stomach. The *intestine* is a coiled tube with its distal part dilated as the *rectum*. The *anus* is located on the ventral surface and in front of the anal fin. The *liver* is a distinct bilobed glandular structure. The bile produced in the liver is stored in the *gall bladder* situated on the ventral side of the right lobe of liver. The bile duct opens into the intestine just near the point of origin of pyloric caeca.

RESPIRATORY SYSTEM

The primary respiratory organs are the four pairs of gills, two pairs on either side. The gills are placed in the *gill chamber* and the gill openings are wide. The structure of the gills is similar to that of Bhetki. The lata fish is capable of living in absence of water for a considerable period of time. When out of water, this fish is able to breathe air by a pair of specialised suprabranchial cavities. The suprabranchial cavities are situated in the gill chambers. These are lined internally by a highly vascular membrane and physiologically functioning as the lungs. These are accessory respiratory structures.

CIRCULATORY SYSTEM

The circulatory system is built on the teleostean plan. The heart is composed of a thin walled *sinus venosus*, an oval muscular *ventricle* and an *auricle*. The conus arteriosus is absent and this region, like that of Bhetki, is marked by the presence of a pair of valves guarding the entrance of the bulbus aorta. The bulbus aorta is noncontractile and represents the dilated base of the ventral aorta. The bulbus aorta and the ventral aorta are covered by a tough membrane.

Afferent Branchial System. The deoxygenated blood from the ventricular cavity is conveyed through a stout median *ventral aorta* to the gills for aeration by four pairs of *afferent branchial arteries*. All the four pairs of the afferent branchial arteries have independent origin from the ventral aorta. The first and second pairs of the afferent branchial arteries are simple straight arteries leading to the corresponding pairs of gills. While the third and fourth afferent branchial arteries of each side cross each other forming a loop after their origin from the ventral aorta (Fig. 5.33).

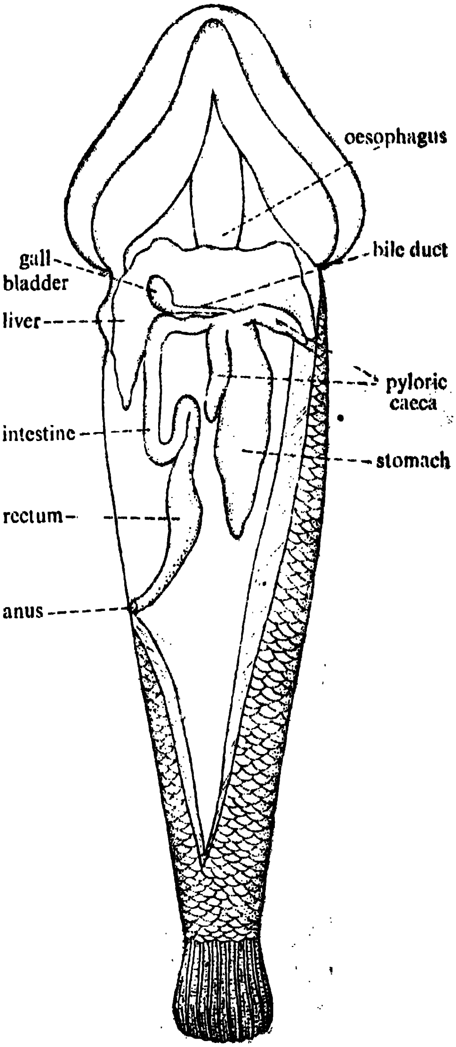


Fig. 5.32. Digestive system of *Channa*.

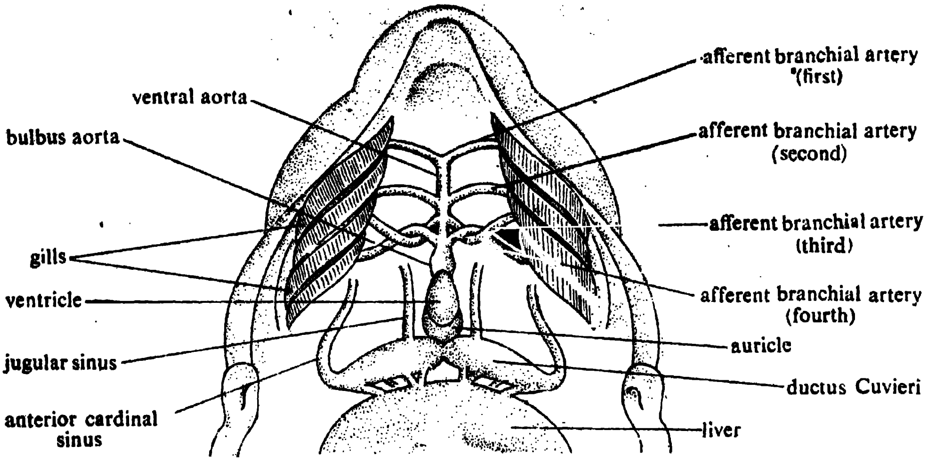

ventral aorta
bulbus aorta
gills
ventricle
jugular sinus
anterior cardinal sinus
afferent branchial artery (first)
afferent branchial artery (second)
afferent branchial artery (third)
afferent branchial artery (fourth)
auricle
ductus Cuvieri
liver

Fig. 5.33. Afferent branchial arteries and anterior veins of *Channa*.

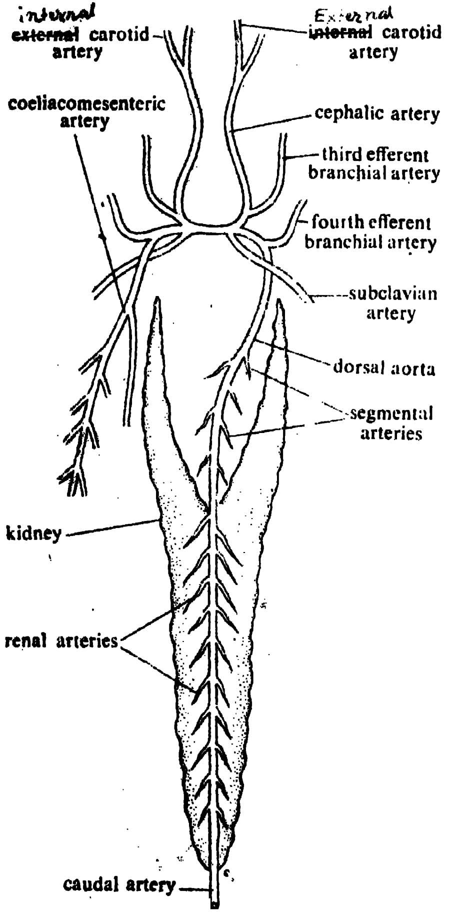

internal
~~external~~ carotid artery
External
~~internal~~ carotid artery
coeliacomesenteric artery
cephalic artery
third efferent branchial artery
fourth efferent branchial artery
subclavian artery
dorsal aorta
segmental arteries
kidney
renal arteries
caudal artery

Fig. 5.34. Efferent branchial arterial system in *Channa*.

Efferent Branchial System. The efferent branchial arterial system is peculiar. The first and second pairs of efferent branchial arteries are lacking (Fig. 5.34). The third efferent branchial artery on each side receives oxygenated blood from the third gill of that side and gives off a *cephalic artery*. This artery runs forward and bifurcates into an *external carotid artery* and an *internal carotid artery*. A transverse artery acts as a connecting bridge between the third and fourth efferent branchial arteries of the two sides. The left fourth efferent branchial artery gives origin to the *dorsal aorta*. The coeliacomesenteric artery originates from the point of union of the transverse artery and the right fourth efferent branchial artery. Two *subclavian arteries* arise independently on the two sides and each divides into two arteries — the *pectoral artery* supplying the pectoral fin and a *pelvic artery* to the pelvic fin. The dorsal aorta occupies a middorsal position and runs posteriorly up to the tail as *caudal artery*. Along its course it gives off paired *segmental arteries*, *gonadal arteries* and *renal arteries*.

The absence of first and second pairs of efferent branchial arteries in Lata is difficult to interprete. The oxygenated blood from the first two pairs of the gills is possibly drained into the suprabranchial cavity directly through some sort of capillary networks. These capillary networks together with that of the suprabranchial cavity unite to form an artery which joins with the cephalic arteries.

The venous system is strikingly similar to that of Bhetki fish.

OTHER SYSTEMS

The nervous system, the organs of special sense and the urinogenital system resemble basically that of Bhetki. Figure 5.35 gives an idea of the origin and distribution of V, VII and X cranial nerves in Lata.

EXAMPLE OF BONY FISH—ROHU

Labeo rohita, commonly called the Rohu fish is one of the typical fresh water bony

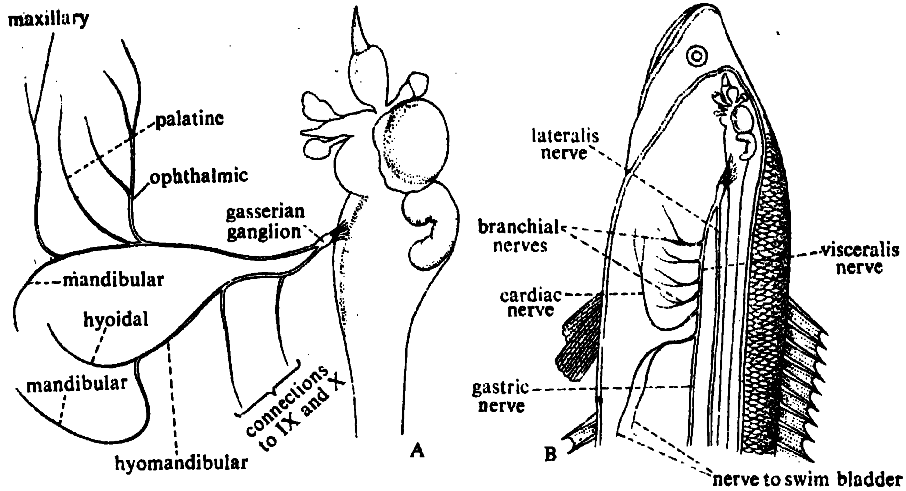

maxillary
palatine
ophthalmic
gasserian ganglion
mandibular
hyoidal
mandibular
hyomandibular
connections to IX and X
A
lateralis nerve
branchial nerves
visceralis nerve
cardiac nerve
gastric nerve
B
nerve to swim bladder

Fig. 5.35. Schematic representation of the origin and distribution of the fifth and seventh (A) and and tenth cranial nerves (B) of *Channa*.

fishes of India. This particular fish is studied as the type specimen of bony fishes in many Indian Universities.

EXTERNAL STRUCTURES

The Rohu fish has a spindle shaped body measuring upto 1 m in length and weighing about 20–25 kgs. The dorsal side of the body is blackish in colour and the ventrolateral sides are silvery. The body, like that of Bhetki, is distinguishable into a conspicuous *head*, *trunk* and post anal *tail* (Fig. 3.36). The head extends from the snout upto the posterior margin of the *operculum*. The snout is depressed and projects beyond the jaws. *Labeo rohita* is characterised by having no lateral lobes in the snout. Two *nostrils* are present on the dorsal side of the snout. The mouth is a crescentic transverse opening bounded by thick fringed lips. Teeth are absent in the jaws. The *eyes* are prominent and are lidless. One or two pairs of *barbels* are present on the dorsolateral sides of the mouth. The *maxillary barbels* are relatively short and delicate than the *rostal barbels*. The trunk is elongated and oval in cross-section. It is covered over by thin overlapping *cycloid scales*. The *lateral line* runs along the lateral sides of the body. The scales along the lateral line contain pores which are connected with a tubular canal. The *vent* is situated ventrally and just in front of the anal fin.

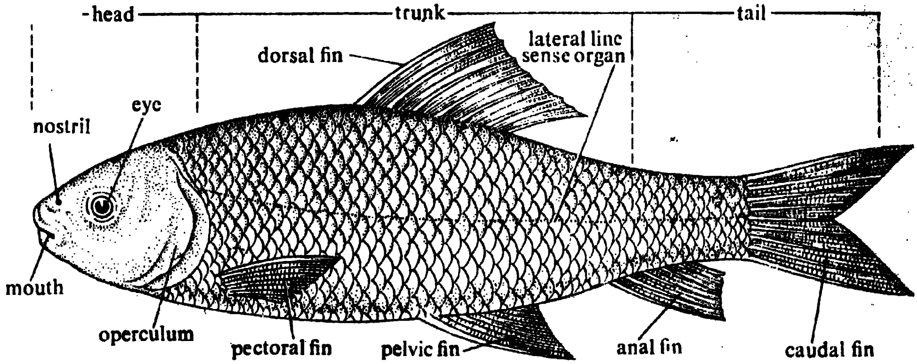

head
trunk
tail
dorsal fin
lateral line sense organ
eye
nostril
mouth
operculum
pectoral fin
pelvic fin
anal fin
caudal fin

Fig. 5.36. External features of *Labeo*. Barbels are not shown.

FINS

Both the paired and unpaired fins are well-developed. The *pectoral* and *pelvic fins* are borne by the respective girdles. The pectorals are located at the anterolateral side of the trunk behind the operculum. Each pectoral fin is supported by 19 fin-rays. The pelvics are situated on the ventral side behind the pectorals. Each pelvic fin contains 9 fin-rays. There is only one dorsal fin in Rohu which arises from the mid-dorsal line of the trunk half way between the snout and the base of the tail. The anal fin lies posterior to the anus. The dorsal fin consists of 13 fin-rays and anal fin has 4–6 fin-rays. The tail fin is homocercal with two symmetrical lobes. Several fin-rays support the tail fin.

SKIN

The integument is covered by an outer soft *epidermis* and an inner *dermis*. The epidermis is composed of epithelial cells with numerous unicellular mucous glands. The musculature of the body wall lies below the integument. The disposition of the body wall musculature is similar to that of other fishes which has already been described.

SKELETAL STRUCTURES

The scales and fin-rays constitute the exoskeleton of Rohu fish. The endoskeleton is completely ossified and consists of (1) an axial skeletal portion and (2) an appendicular skeletal part.

AXIAL SKELETON. The axial skeleton is composed of the skull, vertebral column with the ribs and the skeletal elements supporting the median fins.

SKULL. The skull of Rohu has a very complicated structural organisation. Many investing and replacing bones participate in the formation of the skull (Fig. 5.37). It is composed of the *cranium*, the *sense capsules* and the *visceral arches*. The cranium and the sense capsules are immovably united together while the visceral arches are loosely attached with the skull. Basically the skull is composed of a posterior *basal plate* and an anterior *trabecular* region. The *auditory capsules* are united with the basal plate and the *nasal capsules* are attached with the trabecular region. The lateral walls are mostly incomplete and are derived from the *orbital cartilage.* This cartilage joins posteriorly with the auditory capsule and the nasal capsule on the anterior end. The *palatoquadrate* arch (visceral arch) articulates

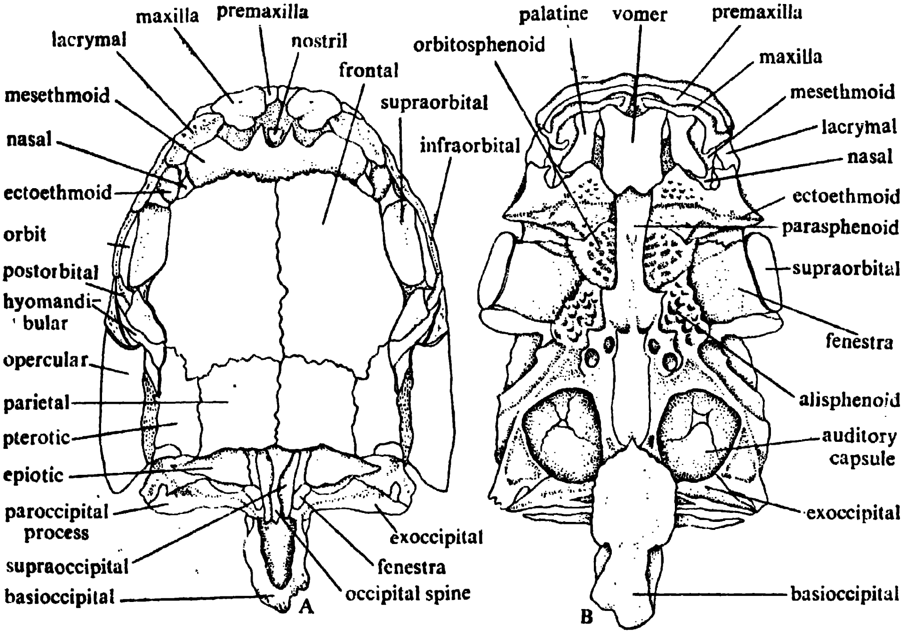

maxilla
premaxilla
lacrymal
nostril
frontal
mesethmoid
supraorbital
nasal
infraorbital
ectoethmoid
orbit
postorbital
hyomandibular
opercular
parietal
pterotic
epiotic
paroccipital process
supraoccipital
basioccipital
exoccipital
fenestra
occipital spine
A
palatine
vomer
premaxilla
orbitosphenoid
maxilla
mesethmoid
lacrymal
nasal
ectoethmoid
parasphenoid
supraorbital
fenestra
alisphenoid
auditory capsule
exoccipital
basioccipital
B

Fig. 5.37. Skull of *Labeo*. A. Dorsal view. B. Ventral view (after Sarbahi).

anteriorly with the trabecular region of the skull by a *basal process* and posteriorly with the auditory capsule by an *otic process*.

The skull in adult assumes an elongated structure. It is broadly divided into (1) a *dorsal roof*, (2) a *posterior occipital* region, (3) the *otic region* consisting of the bones of the auditory capsules, (4) an *orbitotemporal* region and (5) an anterior *nasal* (*ethmoidal*) region. The dorsal side is more or less convex. A shallow *supratemporal* groove is present on its posterodorsal side. This groove extends posterolaterally towards the main *occipital spine*. The posterior wall or the occipital region of the skull bears three apertures, a median *foramen magnum* and two large oval fenestrae. Each fenestra pierces the *exoccipital* bone and forms a characteristic feature of the cyprinoid skull. The occipital region is composed of a *supraoccipital*, a *basioccipital* and a pair of *exoccipital bones*. The main posterior part of the skull is formed by the supraoccipital bone which does not form the dorsal boundary of the foramen magnum in Rohu. It is divided into a dorsal and a posteroinferior portions. The wider anterior end of the dorsal portion is overlapped by the *parietal* bones. A median vertical *occipital spine* is present on the dorsal portion of the supraoccipital. The posteroinferior portion of the supraoccipital is composed of the *occipital spine* (or keel). The exoccipitals are large bones, each consisting of (i) a *basal plate*, (2) a *paroccipital process* and (3) a small *dorsal process*. The basal plate forms part of the floor of the cranial cavity and the paroccipital process forms the posterior boundary of the auditory capsule and the side wall of the cranial cavity. The dorsal process encloses the foramen magnum. The basioccipital is a large bony piece and is roofed over by the occipital condyle. A deep depression is present on the posterior surface of the occipital condyle. A large oval *masticatory process* is borne by the ventral surface of the basioccipital.

The otic region is represented by the paired auditory capsules each situated on the posterior side of the skull and lies between the seventh and the ninth cranial nerves. Each auditory capsule is derived from an otic cartilage growing round the internal ear. The otic cartilage is transformed into the *prootic*, *epiotic*, *sphenotic*, *pterotic* and *opisthotic* bones in other teleosts. But in Rohu the opisthotic bone is lacking and the other four bones form a compact inverted cup-like structure.

The orbitotemporal region of the skull is composed of the *temporal* (or *sphenoidal*) region and the orbit. The temporal region is subdivided into: (*a*) the *parietal* region and (*b*) the *frontal* region. The parietal region is made up of the *parietals*, *alisphenoids* and *parasphenoid*. The frontal region includes the *frontals*, *orbitosphenoids* and *parasphenoid*. Besides these bones, the supratemporal is located at the posterolateral angle of the skull.

The nasal (or ethmoidal) region of the skull comprises of the bones which develop in relation to the nostrils and the snout. The participating bones of this region are the paired *nasals*, *ectoethmoids* and *lacrymals*, a median *mesethmoid*, a *vomer* and a *rostral*. Of these bones, the mesethmoid, ectoethmoid and rostral are replacing bones, while the nasals, lacrymals and the vomer are all investing bones.

VISCERAL SKELETON. The *visceral skeleton* comprises of a series of seven half-hoops encircling the pharyngeal wall. The half-hoops of two sides unite with each other along the midventral line forming seven visceral arches. All the visceral arches are united with one another midventrally to form a basket-like visceral skeleton. The first visceral arch is called the *mandibular arch*, the second is the *hyoid* and the rest five are the *branchial arches*. Of the five branchial arches, four support the gills while the fifth one forms the inferior pharyngeal bones. The inferior pharyngeal bones develop into the masticating plates armed with large teeth. The mandibular arch is divided into a dorsal *palatopterygoquadrate bar* and a ventral *Meckel's cartilage* forming the primary lower jaw. The palatopterygoquadrate becomes closely associated with the cranium and forms the primary upper jaw. The primary upper jaw becomes ossified by the following replacing bones, *palatine*, *metapterygoid* and *quadrate*. Two investing bones *premaxilla* and *maxilla* support the anterior margin of the mouth and together form the secondary upper jaw. Each half of the lower jaw is composed of a small *articular*, a large *dentary* and a small *angular*. Two dentaries unite in the middle line. The hyoid arch is also divided into two parts: upper *hyomandibular* and the lower *hyoid cornu*. The hyomandibular forms the suspensorium by which the jaws are suspended to the cranium. Many investing bones are connected with the hyoid arch and support the operculum (Fig. 5.38A). The bones of the operculum are *opercular*, *preopercular*, *subopercular* and *interopercular*. Each branchial arch is ossified by four replacing bones, *pharyngobranchial*, *epibranchial*, *ceratobranchial* and *hypobranchial*.

VERTEBRAL COLUMN. The vertebral column is a completely ossified structure and composed of 37–38 vertebrae (Fig. 5.38B). The vertebrae are of *amphicoelous* (i.e., both the ends of the centrum bear concavity) type. The vertebral column is distinguishable into the following parts: (1) an anterior trunk region consisting of 21 *trunk vertebrae* (Fig. 5.38C) and bearing movable ribs and (2) a posterior *caudal region*. The vertebrae of the caudal region lack ribs and possess haemal arches (Fig. 5.38D). The first four trunk vertebrae are greatly altered since these vertebrae connect the swimbladder with the internal ear. The last 3 or 4 trunk vertebrae bear posteroventral processes. The last three caudal vertebrae are modified for the support of the caudal fin. The posteriormost caudal vertebra is transformed into an upturned rod-like *urostyle*. It is a solid structure with a ventral groove wherein the proximal ends of the hypourals fit.

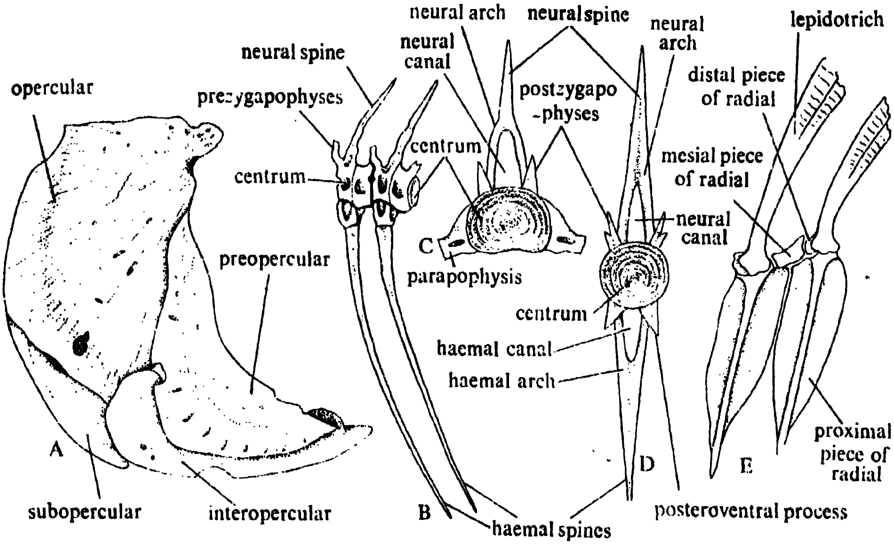

neural arch
neuralspine
neural arch
lepidotrich
neural spine
neural canal
opercular
prezygapophyses
postzygapo -physes
distal piece of radial
centrum
mesial piece of radial
centrum
neural canal
C
parapophysis
preopercular
centrum
haemal canal
haemal arch
proximal piece of radial
A
D
E
subopercular
interopercular
B
haemal spines
posteroventral process

Fig. 5.38. Skeletal structures of *Labeo*. A. Opercular bones. B. Two caudal vertebrae in their normal position. C. A precaudal vertebra. D. A caudal vertebra. E. Showing two radials and fin rays of the dorsal fin (after Sarbahi).

Typical trunk vertebra. A typical trunk vertebra is composed of a deeply biconcave *centrum* (Fig. 5.38C). In the embryonic stage the concavities are communicated by a narrow *notochordal canal* perforating the body of the centrum. The notochordal canal becomes closed in adult. The edges of the centra are united by connective tissue ligaments and the spaces enclosed by the vertebrae are filled with the remains of notochordal elements. A pair of backwardly directed processes arising from the anteriolateral borders of centrum, encloses the spinal cord and unite above to form the *neural arch*. The neural arch gives a long dorsal backwardly directed *neural spine*. A pair of small blunt processes, the *prezygopophyses*, is present anteriorly at the base of the neural arch. Another pair of postzygopophyses arises from the posterolateral edges of the vertebra. The postzygapophyses are pointed upwards and backwards. A pair of short *paraphyses* originating from the ventrolateral surfaces of the centrum is directed downwards. Ribs are attached with the paraphyses by ligaments.

Typical caudal vertebra. The caudal part of the vertebral column is composed of 16 or 17 caudal vertebrae. Like that of a trunk vertebra (Fig. 5.38D), a typical caudal vertebra has (1) an amphicoelous centrum with a median dorsal, a medium ventral and two lateral depressions, (2) a neural arch with a long backwardly directed neural spine and (3) articulating processes like pre- and postzygapophyses, are present in the same position. From the anterolateral margins of the centrum, a pair of backwardly directed processes meets in the midventral line to form a canal for the caudal blood vessels. This process is known as the *haemal arch*. This arch produces a backwardly directed *haemal spine*. A pair of small blunt anteroventral processes is present at the bases of each haemal arch. Similar processes on the posterolateral side of the centrum are present. These posteroventral processes are directed downwards and backwards as seen in posterior trunk vertebrae.

MEDIAN FIN SKELETON. The skeleton supporting the median fin consists of a series of (1) *somactidia* or endoskeletal radials and (2) the *dermotrichia* or dermal fin-rays (Fig. 5.38E). The somactids are parallel bony rods lying embedded within the body muscles. Each somactid is divided into a *proximal*, a *mesial* and a *distal* segment. The dermotrichia support the fold of the fin. In Rohu, the dermotrichia are branched and jointed and are usually called the *lepidotrichia*. Besides these fin-rays, delicate horny-rays (*actinotrichia*) are present at the free edges of the fins.

The dorsal fin is supported by lepidotrichia. There are fifteen or sixteen lepidotrichia seated on fourteen radials. The proximal segment of each radial is enlarged and dagger-shaped. These are called the interspinous bone or *axonost*. The median segment is short and the distal sector is greatly reduced. The anal fin bears a series of eight fin-rays supported by seven radials. The first six are well-formed. The caudal fin is supported by a number of flattened bony rods. Two *epiurals* and a *radial* are present on the dorsal side of the *urostyle* while nine hypourals are present on the ventral side. The fin-rays are attached with the hypourals and epiurals in two symmetrical halves.

Ribs. The *pleural ribs* are segmentally disposed paired slender bony rods. The ribs are attached with the distal ends of the paraphyses. There are seventeen pairs of ribs and the first pair is attached with the paraphyses of the fifth trunk vertebrae. The ribs are present between the muscles and the peritoneum and encircle the abdominal cavity. Besides the ribs, there are series of rib-like Y-shaped intermuscular bones which support the connective tissue septa or myocommas. The intermuscular bones originate from the neural arch of all the vertebrae composing the vertebral column.

APPENDICULAR SKELETON. The appendicular skeleton comprises of the supporting structures of the paired fins and the corresponding girdles (Fig. 5.39).

Pectoral girdle. The pectoral girdle is situated immediately behind the last branchial arch. It consists of a reduced 'primary' endoskeletal and well-formed

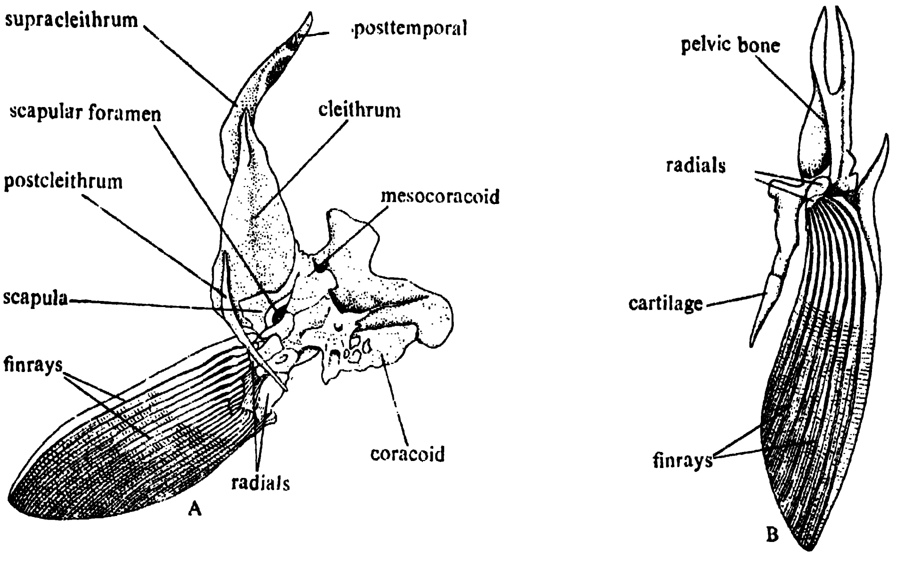


Fig. 5.39. Appendicular skeleton of *Labeo*. A. Pectoral girdle and fin (left half). B. Pelvic girdle and fin (right half), after Sarbahi.

secondary dermal girdle. The primary girdle is composed of two lateral halves, each is transformed into three replacing bones, *scapula*, *coracoid* and *mesocoracoid* (Fig. 5.39A). The two halves of the girdle do not meet in the midventral line. The secondary dermal girdle is composed of investing bones. Each side of this girdle is made up of a *cleithrum* (or clavicle) a *supracleithrum*, a *posttemporal* and a *postcleithrum*. The dermal girdle is attached with the pterotic process of the skull by the posttemporal.

The scapula is a ring like bony piece with a large scapular foramen for the impass of the branchial artery and the nerve. The coracoid is an irregular triangular bone lying internal to the scapula but ventral to the mesocoracoid. The mesocoracoid is an inverted Y-shaped bone. The coracoid and the scapula participate in the formation of the glenoid articulation to which three of the four radials of the pectoral fins are movably attached. The cleithrum of the secondary pectoral girdle is the largest bone and completely covers the primary pectoral girdle. The posterior inner surface of the cleithrum is connected with a curved stout bone, the postcleithrum. The supracleithrum is an elongated dragger-shaped bone which covers the dorsal end of the cleithrum. The supracleithrum is articulated at its dorsal end with a minute conical posttemporal bone which in turn remains attached with the supratemporal bone.

Pectoral fin. The pectoral fin is supported by nineteen lepidotrichia attached with four radials. The radials are articulated directly with the scapula.

Pelvic girdle. The *pelvic girdle* is located anterior to the anal fin. It consists of two similarly constructed halves. Each half is mostly composed of a large osseous pelvic girdle with a small cartilaginous rod attached to the posterior end of the pelvic bone (Fig. 5.39B). The *pelvic bone* is distinguishable into an anterior elongated part and a posterior stout rod-like part. The anterior part bears a ventral deep groove and its frontal end is forked. The forked end is connected with the ribs of the twelveth trunk vertebra by ligaments. The posterior rod-like parts of the two halves of the pelvic girdle are united with the middle line.

Pelvic fin. Each pelvic fin is supported by nine fin-rays and three radials. The fin-rays are attached to the radials proximally and the radials are articulated with posterior border of the pelvic bone. The first two radials bear two fin-rays while the rest are borne by the third radial.

COELOM

The coelom is lined with peritoneum and divisible into an anterior *pericardial cavity* containing the heart and a posterior *perivisceral cavity* accommodating the main viscera.

DIGESTIVE SYSTEM

The digestive system is composed of an extremely long alimentary canal and associated digestive glands (Fig. 5.40). This particular fish is herbivorous in habit. The alimentary canal is divided into the mouth, buccal cavity, pharynx, oesophagus, stomach, intestine and rectum with its external opening, the anus.

The *mouth* is bounded by soft upper and lower lips. The free edges of the lips are broad and are beset with four or five rows of blackish conical papillae. The buccal cavity is a short dorsoventrally compressed cavity with a flat floor and an arched roof. The mucous membrane lining the buccal cavity contains minute papillae. There is no distinct tongue in Rohu, but the mucous membrane lining the floor of the buccal cavity is provided with highly developed thick muscles. The *buccal cavity* leads into a dorsoventrally flattened *pharynx*. The pharynx is bounded by gill-arches and is well-demarcated into an anterior and a posterior portions. The anterior portion is narrower and is perforated laterally by gill-slits. The posterior portion of the pharynx bears closely set pharyngeal teeth on its ventrolateral walls and the ventral wall is highly folded transversely. The pharyngeal teeth help to crush solid foods. These teeth are all alike (homodont) and are arranged in three rows, one alternating the other. Each tooth has a narrow basal root and a cylindrical projecting crown. The root remains embedded in the mucous membrane and the crown is laterally compressed.

The posterior portion of pharynx leads into a very short tube, the *oesophagus*. The mucous membrane of the oesophagus is thrown into a number of longitudinal folds. The *ductus pneumaticus* of the *swim bladder* opens into the oesophagus. The oesophagus leads into the *stomach*. The stomach occupies a position with the coils of the intestine ventral to it and the swim bladder on the dorsal side. The stomach is divided into an anterior *cardiac* stomach and a posterior *pyloric* stomach. The mucous membrane of the cardiac stomach exhibits honeycomb appearance, while that of the pyloric stomach is longitudinally folded. The pyloric stomach passes into the *intestine*. The intestine is extremely elongated (measuring about 7·5 metres) and thin-walled. The intestine is more or less of uniform diameter and forms a number of coils. The mucous membrane of the intestine presents different types of foldings. The anterior portion of intestine shows oblique transverse folds, while the posterior part of the intestine is characterised by having distinct longitudinal folds. The terminal part of the intestine is dilated to form a slightly dilated thinwalled sac called the *rectum*. Like that of the anterior part of the intestine, the mucous lining of the rectum exhibits indistinct oblique transverse folds. The rectum opens to the exterior through the *anus* located just in front of the *urinogenital opening*. The pyloric caeca are lacking in Rohu.

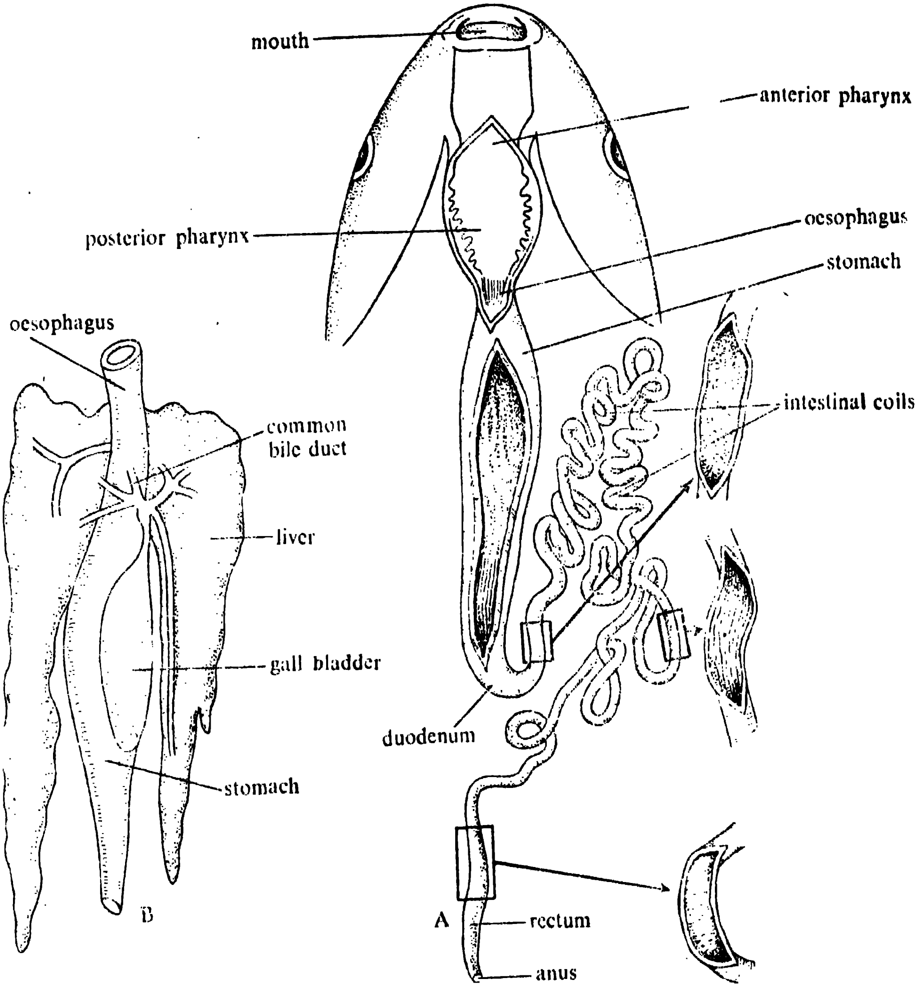


Fig. 5.40. Digestive system of *Labeo*. A. Entire digestive tract. Some regions of the tract are dissected to show the internal details. B. Showing the relationship of the liver with the alimentary canal.

The digestive glands comprise of the *liver* and the *pancreas*. The liver is a massive gland of dark-brown colour. The liver is divided into a narrow right lobe and a broader left lobe. The two lobes of the liver are connected at three regions, anteriorly by a median lobe, medially by a median connective lobe and posteriorly by a median mass. The *gall bladder* is an elongated sac of about 8 cm in length and 2·5 cm in diameter. The gall bladder is located between the right and left lobes of the liver. A cystic duct, after originating from the anteroventral end of the gall-bladder, receives three *hepatic ducts.*

HYDROSTATIC ORGAN

The *swim bladder* is a thin-walled perivisceral gas-filled sac. It lies in the cavity of the coelom and situated dorsal to the gut. The swim bladder is divided into two, an anterior and a posterior chambers. The anterior chamber is connected to the oesophagus by a slender *ductus pneumaticus*. The swim bladder acts as the hydrostatic organ.

RESPIRATORY SYSTEM

Like that of Bhetki, there are four pairs of gills contained in the branchial chambers. Each branchial chamber is covered by operculum. Each *gill* has a double row of *gill-filaments* and is supported by *gill-arch* with *gill-rakers*. The pseudobranch of the hyoid arch consists of a comb-like body. Each pseudobranch is composed of a single row of gill-filaments on the inner surface of operculum. The structure of the gills and the mechanism of respiration are similar to that of Bhetki.

CIRCULATORY SYSTEM

The circulatory system of Rohu is basically built on the teleostean plan as observed in Bhetki. The heart is composed of a *sinus venosus*, an *auricle* and a *ventricle*. The conus arteriosus is absent and is represented by a pair of valves. A noncontractile *bulbus aorta* is present. The sinus venosus is proportionately larger and bears a pair of lateral appendages. It is spongy in nature.

There are four pairs of *afferent branchial arteries*, each supplying deoxygenated blood to the respective gill. The ventral aorta divides anteriorly into the first two afferent branchial arteries. The second, third and fourth pairs of the afferent branchial arteries have separate and independent origin from the ventral aorta.

After oxygenation, the blood from the gills is collected by *efferent branchial arteries*. The venous system, exactly like that of Bhetki, includes the paired anterior and posterior cardinals, unpaired hepatic and renal portal veins and paired subclavian veins. The renal portal vein is well-represented.

NERVOUS SYSTEM

The brain of Rohu is typically built on the piscine plan. The *cerebral hemispheres* are small and undivided. The *corpora striata* are prominent, but the *pallium* is thin and nonnervous. The olfactory lobes are moderately developed. The reduced diencephalon is provided with a dorsal *pineal* body and a ventral *pituitary* body. The *optic lobes* are large with two large *lobi inferiores* on the ventral side. The optic chiasma is absent and the optic nerves simply cross one another. The *cerebellum* is conspicuous and prolongs anteriorly to form the *valvula cerebelli*.

There are ten pairs of *cranial nerves* in Rohu. The origin and branching of the cranial nerves are, as in Bhetki, similarly disposed. The organs of special sense are well-developed and are built on the typical teleostean plan. The sense of taste is highly developed. Numerous taste-buds are present in the lips, in the epithelium lining the first three gill-slits and on the barbels. The *tactile receptors* are abundant all over the body specially on the lips and barbels. The organisation of lateral line system, eyes and ears is strikingly similar to those of other bony fishes already described. The ear is composed of utriculus, sacculus, lagena and three semicircular canals. The otoliths are remarkably large in size and are three in number: (1) *sagitta* is present inside the sacculus, (2) *asterisus* fills the lagena and (3) *lapillus* is present in the utriculus.

URINOGENITAL SYSTEM

The *kidneys* are extremely elongated bodies extending along the whole length of the visceral cavity. These are situated to the dorsal side of the body wall above the swim bladder and are distinct anteriorly but become partly fused in the middle region. The kidneys are of *mesonephric* type. The *ureters*, one from each kidney, open into a thin-walled *urinary bladder* situated ventral to the cloaca. The urinary bladder opens into the urinogenital sinus.

The gonads become greatly enlarged during breeding season. In the males, the *testes* extend the whole length of the abdominal cavity. From the posterior end of each testis, a *vas deferens* arises which finally opens into the urinogenital sinus. In the females, the *ovaries* are also paired structures which attain larger size than the testes. The *oviducts* are lacking. The eggs are released in the body cavity from where the eggs emerge out through a pair of *genital pores* formed temporarily from the anterior wall of the *urinogenital sinus*.

In Rohu, enormous number of eggs are laid at a time and the eggs sink to the bottom. Immediately after discharge the eggs come in contact with the spermatic fluid (milt) and fertilization takes place externally. The mechanism of cleavage and subsequent developmental sequences are not known in Rohu. It is expected that the development should be like that of other bony fishes. *Labeo rohita* is a fast growing carp. The eggs hatch within 2–15 hours. Freshly hatched youngs (hatchlings) have prominent yolk-sac attached on the ventral side of the body. Absorption of the yolk-sac requires 5-7 days and the young ones (called as fry) begin to feed. The fry attains a size from about 2 mm to 3 mm and is characterised by having fringed lips and a prominent vertical dark spot at the base of the tail which disappears in course of growth. When the fry becomes 5 mm long, it is designated as the fingerling which also varies from 5 mm-15 mm in length. Attainment of sexual maturity requires about two years.

EXAMPLE OF BONY FISH—LATIMERIA

Latimeria is a peculiar bony fish belonging to the subclass Crossopterygii. It is the sole surviving representative of the coelacanths. The discovery of this 'living fossil' created a sensational history in the science of fishes. The first living specimen was caught at a depth of about 80 m near the eastern coast of South Africa in the year 1938. The fish was steel-blue in colour and measuring about 1·5 m in length. Miss C. Latimer, the then curator of the museum of East London (South Africa), suspected its peculiarities and preserved the skin of the fish with a special note on its principal characteristics. Professor J. L. B. Smith, a well-known Ichthyologist at Rhodes University of Grahams town identified the specimen as a coelacanth and gave the name *Latimeria chalumnae* after the name of Latimer. Extensive searches have been made to procure live specimens of the particular type of fishes. The second specimen was collected from the Anjouan Island (Madagascar) in 1952. Smith studied the animal in details and suggested a new generic name *Malania*. But a thorough study on the other specimens by Millot and his associates reveal the biology of these fishes and in course of time many other coelacanths have been trawled around Comoro Islands (Madagascar) from the depths of 150–400 m. All these fishes are large in size and weighing upto 80 Kg. It is now unanimously accepted that the generic name of all these coelacanths, discovered so far, will be *Latimeria* and *Malania* as suggested by Smith as a synonym. The knowledge about the anatomy of Latimeria is far from complete and the following account will give a general idea of the group.

EXTERNAL STRUCTURES

The body is covered with *cosmoid* scales. The scales are round and overlap in such a fashion that the body becomes three scales thick. The paired fins act as active swimming organs and are also used for movement at the bottom of the sea. The *paired fins* are of pedunculate type (Fig. 5.41A, C). Each such fin has a short scale-covered lobe and the fin-rays are arranged on the tip in a fan-shaped fashion. There are two *dorsal fins*. The anterior dorsal is supported by a bony plate while the posterior one is almost like that of paired fins. The *tail* is *diphycercal* with a small median lobe. Like that of other teleosts, the fin-rays supporting the fins are highly mobile.

SKELETAL STRUCTURES

The *notochord* persists as a massive unconstricted rod-like structure. The *vertebral column* is represented by a hollow unossified tube with the ossified *neural* and *haemal spines*. The dorsal spines are hollow, hence the name of the group, coelacanths. The *skull* has a well-developed joint between a condyle of the posterior end of *basisphenoid* and a cavity at the anterior end of the occipital region of the skull (Fig. 5.41B). The joint allows movement of the anterior portion of the skull and helps to catch the prey.

DIGESTIVE SYSTEM

The *jaws* and *palate* are provided with numerous minute *teeth*. The *buccal cavity* is spacious and leads into a powerful muscular *oesophagus*. The oesophagus leads into a large bag-like *stomach*. The *intestine* is spiral and continues as the *rectum* and *cloacal pouch*. The intestine contains a complicated *spiral valve*. A median *nodular organ* (homologous with the rectal gland of selachians) is present which pours its secretion into the cloaca. The cloacal pouch bears a *urinogenital papilla*. The *liver* is a bilobed structure with an enlarged *gall bladder*. The *pancreas* is well-formed.

SWIM BLADDER

The *swim bladder* is variable in size and shape in different individuals. It arises as a tube of 3–8 cm in length from the ventral side of the oesophagus and continues backwards to occupy the dorsal side of the abdominal cavity. The cavity of the swim bladder is greatly reduced and contains about 95% fatty tissue. The flesh of Latimeria is also excessively oily in nature. The swim bladder is neither a hydrostatic nor a respiratory organ.

RESPIRATORY SYSTEM

Respiration takes place by the *gills*. There is a deep *spiracular pouch* in Latimeria which lacks mandibular pseudobranch and external opening. The gills are composed of a small *hyoidean hemibranch* on the posterior surface of the hyoid arch and four *holobranchs*. The fifth branchial arch is greatly reduced and lacks gill.

CIRCULATORY SYSTEM

The *heart* is a very simple structure. It is composed of *sinus venosus* and *auricle* located behind the *ventricle* and *conus arteriosus* which bears four rows of endocardial thickenings on its inner wall. These thickenings represent the *pseudovalves* or reduced valves. Presence of such valves speaks about the primitive condition. The *red blood cells* are large in size resembling that of dipnoans and amphibians.

NERVOUS SYSTEM

The *brain* is small and occupies less than one-hundreth part of the cranial cavity. The rest of the space is filled up with fatty substance. There is a large *corpus striatum* in the forebrain and the roof is very thin.

SENSE ORGANS

Besides the *eyes*, *internal ears* and *lateral line sense organs*, there are two peculiar sense organs in the rostral region (Fig. 5.41D). A large sac-like median organ of unknown function communicates with the

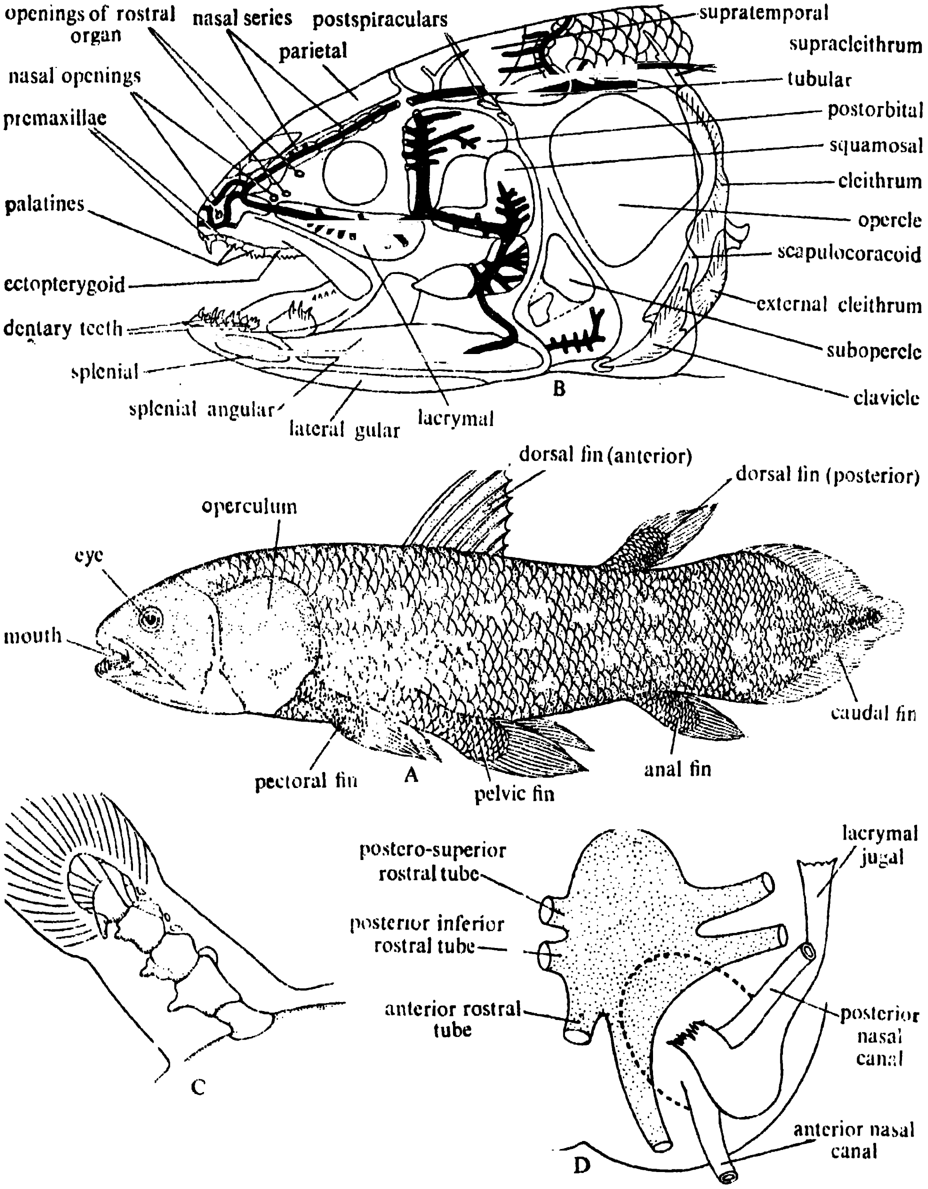

openings of rostral organ
nasal series
postspiraculars
parietal
nasal openings
premaxillae
palatines
ectopterygoid
dentary teeth
splenial
splenial angular
lateral gular
lacrymal
B
supratemporal
supracleithrum
tubular
postorbital
squamosal
cleithrum
opercle
scapulocoracoid
external cleithrum
subopercle
clavicle
dorsal fin (anterior)
dorsal fin (posterior)
operculum
eye
mouth
caudal fin
pectoral fin
A
pelvic fin
anal fin
C
postero-superior rostral tube
posterior inferior rostral tube
anterior rostral tube
lacrymal
jugal
posterior nasal canal
anterior nasal canal
D

Fig. 5.41. Structures of *Latimeria*. A. External structures. B. Anatomy of the head region. C. Dorsal view of the skeleton of pectoral fin. D. Rostral sensory organ.

exterior by three *rostral tubes* on each side of the snout. The *rostral organ* is not connected with the olfactory organ and is filled up with a gelatinous substance. It bears similarity with the ampullae of Lorenzini. The rostral organ is innervated by the superficial ophthalmic nerve. The other sensory organ is olfactory in function. It is a paired structure and communicates with the exterior by nasal tubes.

URINOGENITAL SYSTEM

The *kidneys* are fused to form a median structure and remain attached to the ventral wall of the abdominal cavity. The ventral position of kidney is a peculiar occurrence and not found in other vertebrates. There are two *ureters*, each of which dilates into an expanded bladder. The ureters open into the *urinogenital papilla*. The *gonads* are usually paired and the *gonoducts* open between the bases of the pelvic fins.

ZOOLOGICAL IMPORTANCE OF LATIMERIA

The crossopterygians constitute a peculiar collection of fishes which throw much light on the problems of the origin of land vertebrates. The coelacanths, a side line of the crossopterygians, draw a special interest because these fishes survived for much longer period of times than any other vertebrate forms. Originating from the common crossopterygian ancestor possibly in the late Devonian, they lived almost without any significant change for such a long span of time. The first coelacanth fossil, *Coelacanthus*, was discovered in Carboniferous and that of *Undina* during Mesozoic era. Coelacanthus was a fresh water form and Undina was marine. Many fossil forms of the Mesozoic era have been discovered. No coelacanth was recorded beyond Mesozoic era. It was then naturally thought that the group to have become extinct for about 50,000,000 years. But the discovery of a living example of the group, *Latimeria* in the year 1938 added a new dimension to our knowledge. Latimeria persists since the Jurassic time or earlier with very little change. The anatomical organisation of Latimeria is very peculiar and presents the development of structures parallel to those of the Teleostei rather than the dipnoans with which it shares its ancestry. What causes Latimeria to remain practically unchanged for such a long period of time is not understood. Several features are found to be paedomorphic in Latimeria, which may be responsible for such a long survival.

EXAMPLE OF BONY FISH—DIPNOI

The dipnoans are generally called the 'lung fishes'. The group, Dipnoi owes its name from the presence of two internal nostrils. Standing on the basic piscine platform, dipnoans possess many interesting features that the early fishes have gone through to become the land vertebrates, especially

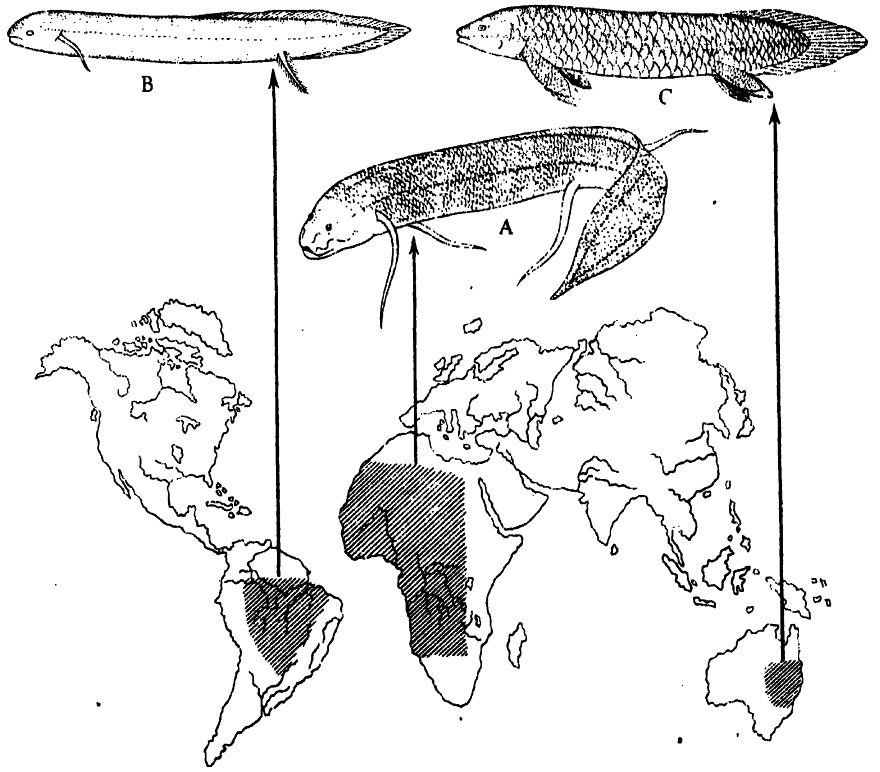


Fig. 5.42. Showing the discontinuous distribution of the living dipnoans. (A) *Protopterus*, (B) *Lepidosiren* and (C) *Neoceratodus*. Note that *Lepidosiren* is present in South America, *Protopterus* in Africa and *Neoceratodus* in Australia.

the amphibians. This makes the systematic position of the group controversial. The dipnoans evolved during the middle Devonian and flourished well in the Permian and Triassic periods. They became rare after Triassic and survived now by three specialised genera.

GEOGRAPHICAL DISTRIBUTION

The fact that closely related species exist in widely separated places without having any form in the intermediate territories, presents problems which are difficult to interprete. The same is true in case of the dipnoans living to-day. The dipnoans are represented by three surviving genera, *Neoceratodus* in Australia (only in the Burnett and Mary rivers of Queensland), *Protopterus* in tropical Africa (ranging from the river Senegal, White Nile, Lake Tanganayika and Zambesi river) and *Lepidosiren* in tropical South America (in river Amazon and its tributaries) (Fig. 5.42). Protopterus and Lepidosiren belong to a same family, Lepidosirenidae and Neoceratodus is the only genus of the family, Ceratodontidae. It is apparent that despite of the oceanic barriers separating them, the living dipnoans have special relationship. The palaeontological records show that the dipnoans were once enjoyed almost world-wide distribution. Their persistence in the Southern parts of the globe and their complete absence from Asia can be explained on the assumption that the southern parts became separated from Asia before the evolution of the dipnoans.

HABIT AND HABITAT

The three living dipnoans inhabit the rivers and are also capable to breathe air by the 'lungs'. Protopterus lives in large lakes and rivers of tropical Africa. It can survive when the rivers become completely dried up in summer. It can dig into the mud and aestivate (summer sleep) there for at least six months in a 'cocoon' made out of clay and mucus (Fig. 5.43). The mouth of the cocoon is closed by a lid which is perforated by a minute pore for carrying out breathing. During the period of aestivation, nutrition is supplied by the stored fat. Transhipment is possible from one place to other when the fish is enclosed in a cocoon. This habit of aestivation is adopted by the group since the Permian period. This fact is attested by the remains of cylindrical burrows associated with fossilised dipnoan bones. Lepidosiren has also the property of aestivation to escape death during the summer. It lives in rivers which become shallow and stagnant in summer, but never dried up completely. It lives mostly at the bottom of the river. During summer when the water level becomes low and toxic due to the decomposition of the organic materials, Neoceratodus can thrive well by switching over to the pulmonary respiration. When the water is plenty and oxygen is easily available, Neoceratodus adopts gill respiration. Neoceratodus dies if it is taken out of water.

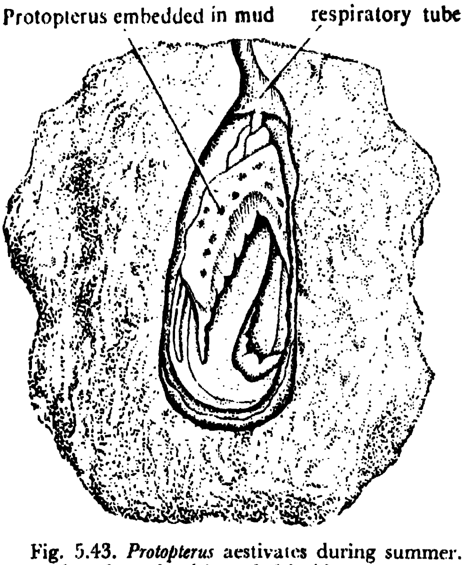


Fig. 5.43. *Protopterus* aestivates during summer. Note that the animal is curled inside a water proof cocoon with a respiratory tube running from the mouth to the tunnel.

All the surviving genera of the lung fishes are sluggish in nature and are bottom dwellers. They are carnivorous, although Lepidosiren sometimes feeds on plant materials. It lives mainly on snails. Protopterus is predaceous in nature and feeds on worms, crustaceans, insects, frogs and many other small animals. These fishes are often found to attack their own species and bite off portions of the limbs, tail and other parts of the body. The lost parts are capable of regeneration. Neoceratodus is also a carnivorous fish which devours molluscs, crustaceans and other worms.

In Lepidosiren and Protopterus, parental care is present. The eggs are laid in the muddy nests. The nest is simply a tunnel of about 30 cm deep. The males usually guard the nest till the development is complete. The parental care is highly specialised in Lepidosiren when the pelvic fins become specially modified during breeding season. The pelvic fins become greatly enlarged and highly vascularised. The significance of such modification is either to release excess of oxygen to the surrounding water for the respiration of the developing youngs or possibly act as accessory respiratory structure to compensate aerial respiration while remaining around the nest.

EXTERNAL STRUCTURES

The three extant dipnoans have elongated piscine body covered by the overlapping *cycloid scales*. The scales are thin, but in the fossil genus *Dipterus*, the scales are thick and covered by cosmine. The *dorsal*, *anal* and *tail fins* are continuous and are supported by partly calcified fibre-like rays called the *camptotrichia*. Two small dorsal fins are present in Dipterus. The *pectoral* and *pelvic fins* are usually designated as the 'limbs'. These are extremely elongated, filamentous and are devoid of fin-rays. These are highly mobile and help in 'walking' along the bottom by using the so-called limbs as the 'legs'. The paired fins in all of them are typically of 'archipterygial' types having an *axis* with two rows of *radials*. The tail is *diphycercal* in the living genera, but in Dipterus it is *heterocercal* with a small epichordal lobe. The *operculum* and a slit-like *branchial aperture* are present on either side. The spiracles are absent. The external nostrils are enclosed with the upper lip and two internal nostrils open into the mouth cavity. The *lateral line sensory system* is well-developed. The *cloacal aperture* lies at the root of the *tail*. Two *abdominal pores* usually open into the cloaca.

SKELETAL STRUCTURES

The internal skeleton in the dipnoans is largely cartilaginous in nature. It is composed of axial and appendicular skeleton.

Axial Skeleton. The *notochord* persists as an unconstricted rod and is ensheathed by tough fibrous covering. The *vertebrae* are represented by paired *neural* or *basidorsal* and *basiventral cartilages* which form the *neural arches* in the trunk and both the neural and *haemal arches* in the tail region respectively. The vertebrae lack *centra*. Distinct joint between the skull and vertebral column is lacking. The *pleural ribs*, like that of others teleosts, are present in the body wall..

The skull shows the tendency towards reduction of bones in the roof. The anterior part of the roof is incomplete. The roof and walls of the cranium are mostly composed of *parietals* and *frontals*. The cranial floor is formed by the *parasphenoid*. The parasphenoid is expanded and assumes rhombic shape. The *premaxillae*, *maxillae* and *nasals* are totally absent. The *vomer* is narrow. The jaw suspension is *autostylic*, because the *mandible* is attached with the skull by a *palatoquadrate*. The lower jaw is composed of paired *Meckel's cartilages*, tooth-bearing *coronoid* and *supraangulars*. In Neoceratodus, the vestigial dentaries are present. The hyoid and branchial arches are all cartilaginous in nature. The branchial arches bear the gill rakers.

Appendicular Skeleton. The pectoral girdle consists of a stout cartilage with a pair of investing bones, the *cleithra* and *infraclavicle*. The pectoral girdle is attached to the skull by ligament. The pelvic girdle is composed of a cartilaginous plate with a long *epipubic* and *prepubic processes*. Each pectoral fin consists of a long *basal cartilage*, a *central axis* with rows of jointed cartilaginous radials. The central axis is made up of small cartilaginous pieces with *preaxial* and *postaxial radials* on the sides. The pelvic fin has the similar structure except that the preaxial radials are lacking.

DIGESTIVE SYSTEM

The food of the lung fishes consists largely of the invertebrates (specially the molluscs) and decomposed vegetation. The teeth form characteristic *tooth-plates* for crushing the molluscan shells. The tooth-plates are formed by the fusion of many small *denticles*. The tooth-plates are borne on the bony plates. Each tooth-plate is produced into three major cusps. The shape and disposition of the tooth-plates depend on the degree of adaptation to crushing and shearing the molluscan body. The alimentary canal is a simple tube. The *pharynx* leads into an *oesophagus*. The lung fishes lack distinct *stomach*. The posterior region of the oesophagus shows slight dilatation which is regarded by many as a part of the stomach (Fig. 5.44A). The cavities of the stomach and intestine are separated by a flap-like *pyloric valve*. The intestine is ciliated and contains a *spiral valve* running along the entire length of the intestine and makes about six and a half turns (Fig. 5.44C). The spiral valve ends to a short distance from the cloacal aperture. This portion is designated the *rectum* which opens into a small cloaca. The *cloaca* extends upward to the *urinogenital papilla* and then forwards as a closed bladder (*rectal gland*). The cloacal aperture is situated on the left side of the median fin.

The *liver* is a single massive gland which is slightly divided into two unequal lobes. The liver lies ventrally to the right side of the stomach. The *gall bladder* is large and situated on the left margin of the liver. The *pancreas* remains embedded within the walls of the gut. The *islets of Langerhans* have not seen in the pancreas of the dipnoans. The *spleen* is composed of vascular tissue and is attached to the right dorsolateral wall of the stomach. The alimentary canal exhibits little histological difference and the whole of the gut is lined by columnar, ciliated and goblet cells. The gut, particularly its posterior portion is kept in position by a ventral mesentery which is attached to the ventral body wall.

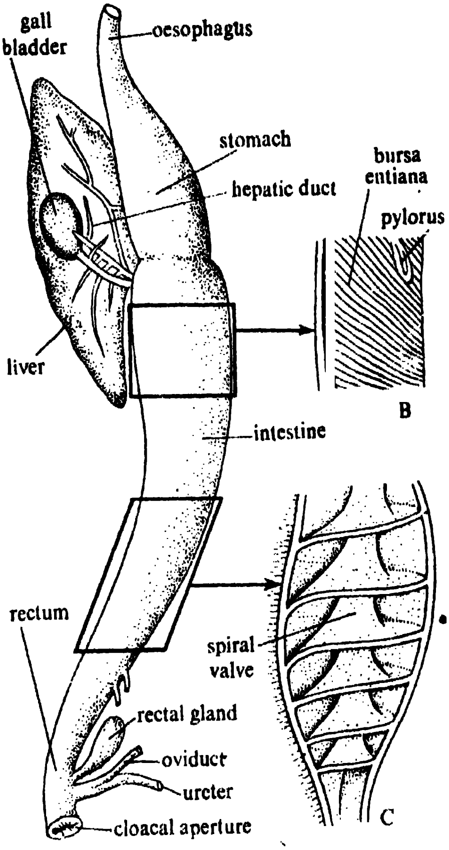


Fig. 5.44. Digestive system of *Protopterus*. A. Showing the alimentary canal and its relation to the liver. B. A portion of the anterior part of the intestine is cut opened to show bursa entiana. C. A part of the intestine is dissected to show the spiral valve.

RESPIRATORY SYSTEM

Both the gill and pulmonary respiration take place in the lungfishes. Although the dipnoans possess the gills as well as lungs, they use mostly the lungs. The nostrils help in aerial respiration. The external nostrils lie at the margin of the mouth and the internal nostrils open into the buccal cavity. A slit-like *glottis* is present in the floor of the oesophagus which opens into a short *trachea*. The trachea passes into the lungs around the right side of the oesophagus. The glottis is provided with a fibrocartilaginous plate which resembles the epiglottis.

The swim bladder is modified into the 'lung' which is similar to that of other tetrapods in structure and function. The main difference lies in its topography. The lung is placed dorsal to the gut while in the tetrapods it is ventral. The dorsal position of the lung in the dipnoans is regarded to be the result of shifting from its original ventral to the dorsal side. The walls of the lungs contain muscle fibres and the internal cavity produces numerous alveoli which lead into minute *alveolar sacs*. In Protopterus and Lepidosiren the supply of blood to the lungs is elaborate. The blood is supplied to the lungs by the sixth embryonic right afferent branchial arch as seen in amphibians. The blood from the lungs is returned by a special pulmonary vein.

The aquatic respiration takes place by the gills. The gill structure is similar in many respects to that of other crossopterygians except the absence of *mandibular pseudobranch* and having only a vestigial *mandibular pouch*. Neoceratodus, the most aquatic of the dipnoans, possesses an *hyoidean hemibranch* and four *holobranchs*. In the lungfishes which depend more on the aerial respiration, the gills help in the excretion of carbon dioxide. Protopterus and Lepidosiren obtain 98% of their oxygen from the air.

CIRCULATORY SYSTEM

The circulatory system is highly developed. The blood is composed of all the cellular entities observed in the higher vertebrates. The introduction of pulmonary respiration in the lungfishes results into the attainment of much complicacy in the cardiac structure. The heart is enclosed in a stiff *pericardium*. The heart is situated somewhat posterior to the gills. The heart of Protopterus and Lepidosiren is typically built on the same plan, but in Neoceratodus the heart is slightly different (Fig. 5.45.)

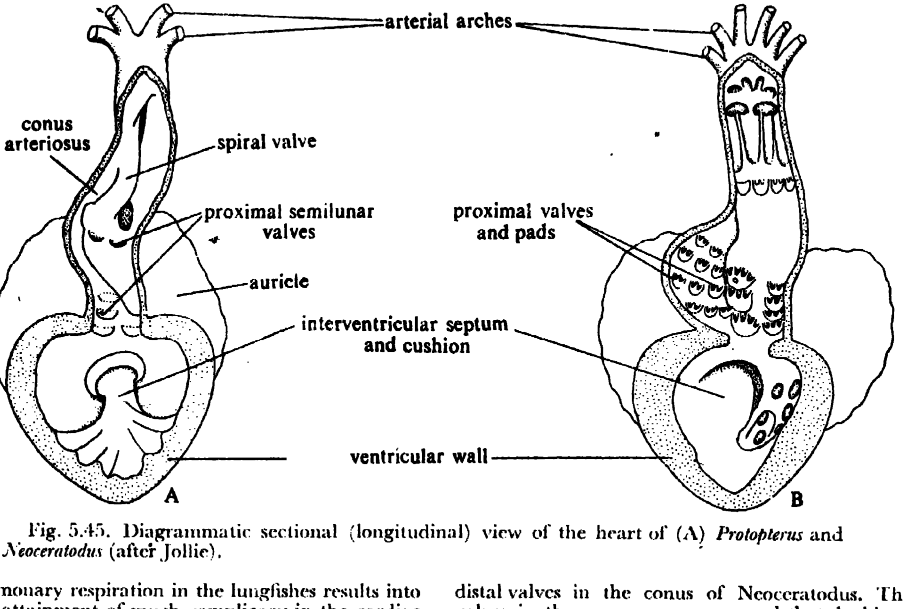


Fig. 5.45. Diagrammatic sectional (longitudinal) view of the heart of (A) *Protopterus* and (B) *Neoceratodus* (after Jollie).

The **HEART** of the lungfishes consists of four chambers, the *sinus venosus*, *auricles*, *ventricle* and *conus arteriosus*. The sinus venosus is incompletely divided into two parts. It opens into the auricle by a broad *sinuauricular opening*. The auricle becomes dilated on either side of a thin and perforated *interauricular septum*, i.e., the cavity of the auricle is almost divided. As the septum contains pores, the blood of the two auricular cavities becomes mixed up. The right cavity of the auricle receives venous blood from the sinus venosus while the left cavity gets oxygenated blood from the pulmonary vein. The pulmonary vein from the lungs passes through the sinus venosus. The auricles are communicated with the ventricle by a large *auriculoventricular aperture*. This aperture is plugged by a large fibrous cushion called the *auriculoventricular cushion*. It is continued into the ventricular cavity as an incomplete interventricular septum. Although the ventricle appears to be divided into two parts by the presence of septum, the ventricular cavity is single and lies anterior to the so-called interauricular septum. The presence of auriculoventricular cushion is peculiar and the auriculoventricular aperture may be opened or closed by raising or lowering the cushion. The conus arteriosus becomes spirally twisted and the cavity becomes complicated by the presence of valves. The *spiral valve* is present which begins ventrally and extends forward to the anterior end of the conus. Three rows of *proximal valves* are present in the conus of Protopterus and Lepidosiren. But in Neoceratodus the conus lacks the spiral valve and a series of semilunar valves marks the course. There are a few rows of proximal and two rows of distal valves in the conus of Neoceratodus. The valves in the conus are so arranged that the blood from the right side of the auricle is directed into the last two branchial arches and that from the left side into the first two. By this way a tendency towards the separation of systemic and pulmonary circulations is achieved.

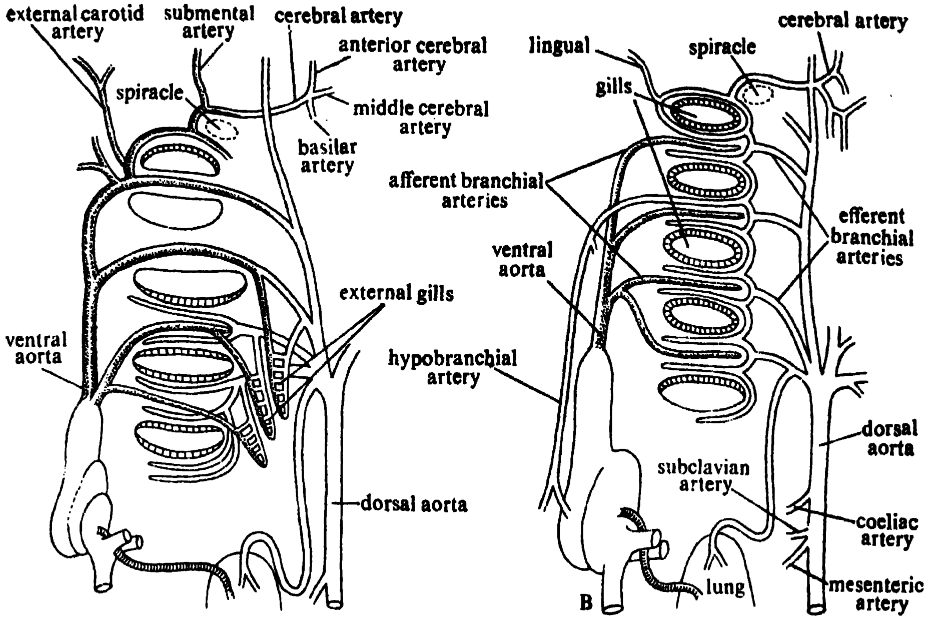

external carotid artery
submental artery
cerebral artery
anterior cerebral artery
spiracle
middle cerebral artery
basilar artery
afferent branchial arteries
external gills
ventral aorta
hypobranchial artery
dorsal aorta
lingual
spiracle
cerebral artery
gills
efferent branchial arteries
ventral aorta
dorsal aorta
subclavian artery
coeliac artery
lung
mesenteric artery
B

Fig. 5.46. Schematic diagram of the anterior part of the aortic arches and their branching in (A) *Protopterus* and (B) *Neoceratodus* (after Jollie).

The lungfishes possess inconspicuous *ventral aorta* and the four *afferent branchial arteries* arising from the anterior end of the conus immediately outside the *pericardium* (Fig. 5.46). The afferent artery carrying blood to the hyoidean hemibranch originates from the first one.

The ARCHES bearing gills are provided with afferent and efferent branchial divisions. Two efferent branchial arteries from each gill bearing arch join to form four *epibranchial arteries*. These four epibranchial arteries of either side join to form a single median *dorsal aorta*. The *pulmonary arteries* carry the blood to the lungs. Neoceratodus is peculiar by lacking the second efferent branchial vessel. In all the lungfishes, a *coronary artery* is present which arises from the anterior efferent branchial arches.

The VENOUS SYSTEM presents certain advanced features which are not observed in other fishes (Fig. 5.47). The blood from the anterior part of the body is returned to the heart by two *precavals* or *ductus Cuvieri*. Each precaval is formed of an *inferior jugular*, *anterior cardinal* and *subclavian* veins. But the left precaval, in addition to the three veins, receives the *posterior cardinal vein*. The posterior parts of both the posterior cardinal veins constitute the *renal portal veins* and are connected by interconnecting cross channels. Presence of an *inferior vena cava* is a characteristic feature in the venous system of lungfishes. This vessel collects majority of the blood from the posterior part of the body and conveys it directly to the sinus venosus. The inferior vena cava enters into the liver and also receives the *hepatic veins*. The hepatic portal drains the intestine by the *subintestinal* and *infraintestinal veins*. Both the inferior vena cava and the left posterior cardinal vein have formed by the *renal veins* draining blood from the kidneys. Both these veins receive *segmental* and *genital veins* in their way to the heart. The blood from the tail region is carried by a *caudal vein* which is bifurcated into two

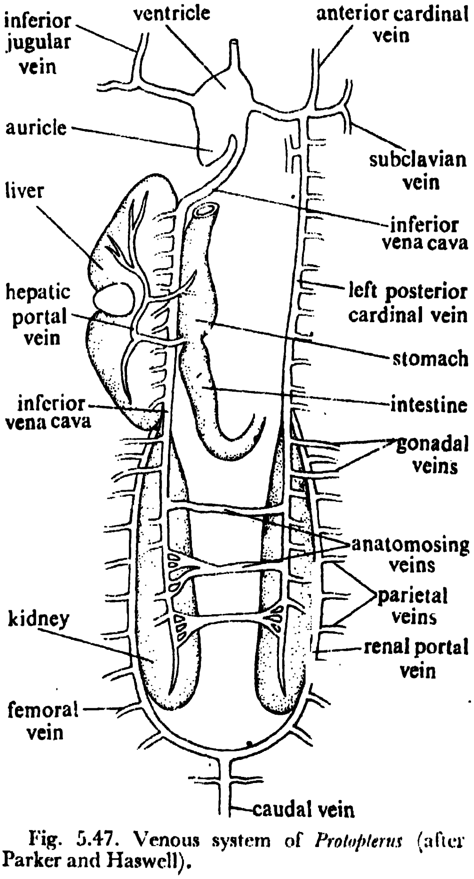

inferior jugular vein
ventricle
anterior cardinal vein
auricle
subclavian vein
liver
inferior vena cava
hepatic portal vein
left posterior cardinal vein
stomach
intestine
inferior vena cava
gonadal veins
anatomosing veins
parietal veins
kidney
renal portal vein
femoral vein
caudal vein

Fig. 5.47. Venous system of *Protopterus* (after Parker and Haswell).

renal portal veins. The renal portal veins break up into capillaries inside the kidneys. In Neoceratodus, the caudal vein opens into the inferior vena cava and not into the renal portal veins as seen in other two genera. In Neoceratodus, the renal portal vein is connected by a *ventral abdominal vein* and the caudal vein by the *lateral cutaneous veins*.

The *pulmonary veins* carrying blood from the lungs unite to form a common *pulmonary vein* and opens into the left auricle. The venous system presents many peculiarities and the posterior portion shows an intermediate stage between that of Chondrichthyes and Amphibia.

NERVOUS SYSTEM

The brain of lungfishes (Fig. 5.48) shows many characteristics resembling that of amphibians. The *telencephalon* becomes evaginated into a pair of well-marked *cerebral hemispheres*. These are elongated structures and united at the posterior ends but are distinct anteriorly. The *olfactory lobes* are sessile and lie dorsal to the anterior ends of the cerebral hemispheres. The roof of the cerebral hemispheres is thin but nervous in nature. The diencephalon is relatively small and its roof is formed of a large mass of choroid tissue, the *saccus dorsalis*. A *pineal body* is present on the saccus dorsalis and its stem extends back towards the *posterior commissure*. The *hypothalamus* bears small *inferior lobes*. The optic lobes are slightly developed and become fused to form single oval mass in front of the cerebellum. The cerebellum is small and forms a narrow transverse ridge. The roof of the diencephalon is covered over by *anterior plexus* which projects into the third ventricle while the fourth ventricle is formed of *choroid plexus*. The brain of Neoceratodus is slightly different and the cerebral hemispheres are smaller in size and the roof is membranous. In Neoceratodus the optic lobes are slightly separated and form paired lobes.

A peculiarly lobed *saccus endolymphaticus* (or *endolymphatic sacs*) lies above the *medulla oblongata*. This is formed by the backward extension of the internal ear and the significance of this structure is not known.

The cranial nerves are basically similar to that of other teleost. A sympathetic nervous system is associated with the vagus nerve. An ill-developed lateral line sense organ is present. In the living dipnoans this system resembles closely that of amphibian larvae. The sensory organs are placed in grooves in Protopterus, while in others these are lodged inside the canals in the skin. But the pattern of development of this lateral line sensory system is basically same in the lung fishes.

ENDOCRINE SYSTEM

The adrenals of dipnoans are represented by *interrenal* and *chromaffin* tissues. These tissues become intermingled and are situated along with the venous channels on the ventral aspect of the kidneys. These tissues function like the adrenals of the higher forms, specially that of mammals.

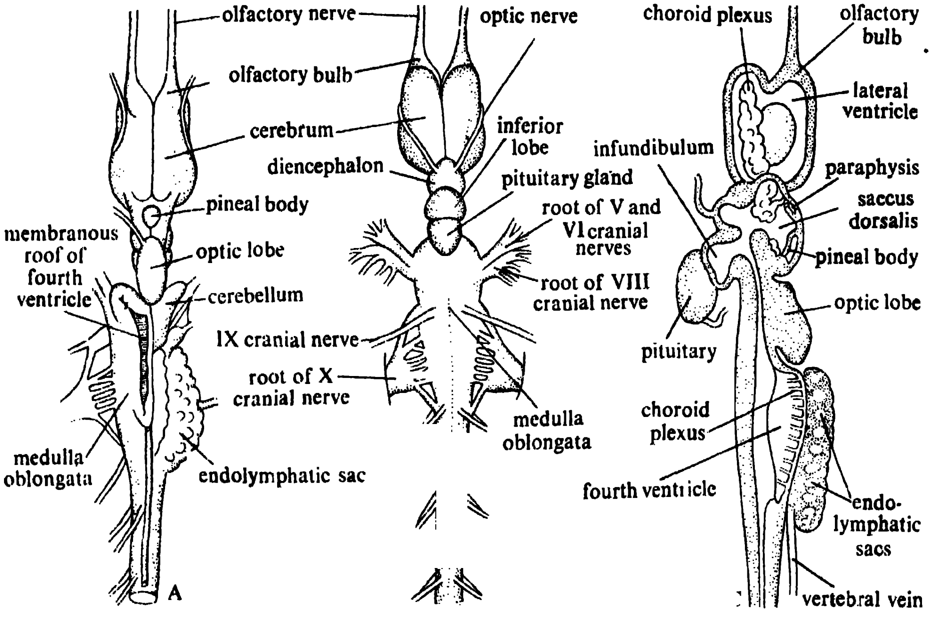

olfactory nerve
olfactory bulb
cerebrum
diencephalon
pineal body
membranous roof of fourth ventricle
optic lobe
cerebellum
IX cranial nerve
root of X cranial nerve
medulla oblongata
endolymphatic sac
A
optic nerve
inferior lobe
pituitary gland
root of V and VI cranial nerves
root of VIII cranial nerve
medulla oblongata
choroid plexus
olfactory bulb
lateral ventricle
infundibulum
paraphysis
saccus dorsalis
pineal body
optic lobe
pituitary
choroid plexus
fourth ventricle
endo-lymphatic sacs
vertebral vein

Fig. 5.48. Brain of *Protopterus*. (A) Dorsal view. (B) Ventral view. (C) Diagrammatic longitudinal sectional view (after Jollie).

EXCRETORY SYSTEM

The excretory system comprises of a pair of elongated *kidneys* which are separate anteriorly but are usually fused on the posterior ends. But in Lepidosiren, the posterior portions of the kidneys remain separate. The kidneys are of mesonephric type and remain in intimate contact with the gonads. As the spermatozoa pass out through the kidney tubules, this particular type of kidney is designated by Greham Kerr as the *opisthonephros*. The kidneys extend throughout the greater part of the visceral cavity. Two thick-walled ducts, one from each kidney, may unite in Neoceratodus or may remain separate in Protopterus and Lepidosiren before opening into the *cloaca*. A *cloacal bladder* is present on the dorsal side. The lung fishes normally excrete 30–70% of nitrogenous waste products through the gills in the form of ammonia. But during aestivation, the nitrogenous waste products are stored in the form of nontoxic urea because the cloacal aperture becomes closed by the cocoon.

REPRODUCTIVE SYSTEM

The sexes are separate. The sexual dimorphism is absent excepting Lepidosiren where the males develop vascular papillae on the pelvic fins during the breeding season.

Male Reproductive Organs. There are two elongated testes in lungfishes (Fig. 5.49B). In Lepidosiren and Protopterus, the testes are narrow bodies and are round in cross-section. But in Neoceratodus the testes are thick and triangular in cross-section. The testes are enclosed by the fatty tissue and lie on the ventrolateral sides of the kidneys. In Protopterus the anterior half of the testis remains in contact with the body wall while its posterior half is suspended by *mesorchium*. The testes of Protopterus are proportionately larger in size than that of Lepidosiren and extend the whole length of the body cavity. The testes are attached with the kidneys dorsally. The anterior end of the right testis in the dipnoans is attached with the liver while the left one extends far forward. The *vasa differentia* (numbering about six in Lepidosiren and Neoceratodus) open into the kidney ducts. But in Protopterus two vasa differentia unite at the posterior end. The Mullerian ducts are usually reduced. In Lepidosiren and Protopterus the anterior end of the Mullerian duct bears an opening in the larval stage while in adult it is closed. These ducts do not open into the *urinary sinus*. In Neoceratodus, the Mullerian ducts of the two sides fuse to form a common sinus and ends blindly in the cloaca.

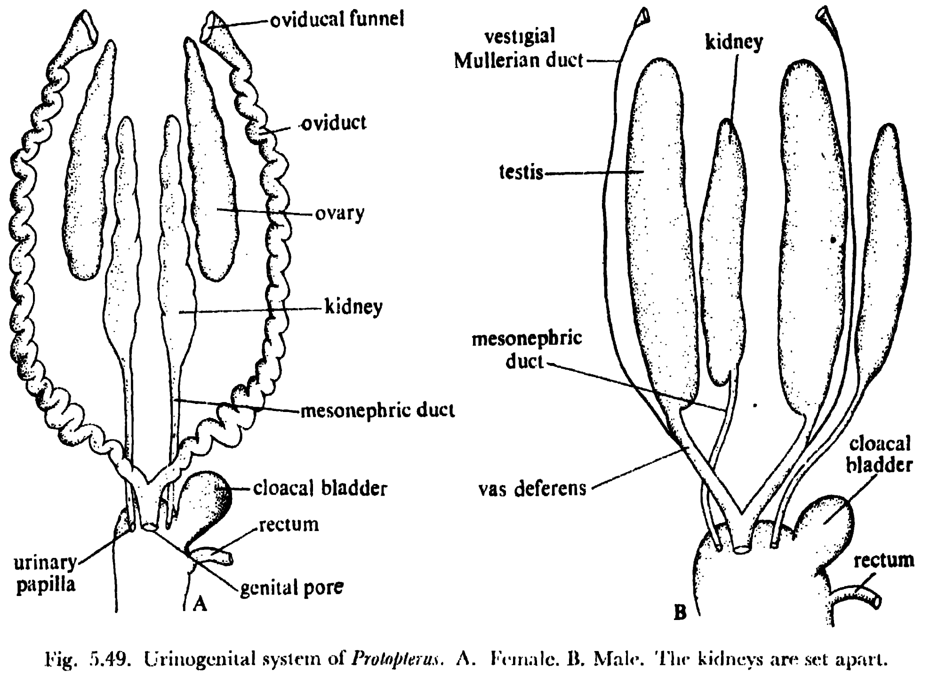


Fig. 5.49. Urinogenital system of *Protopterus*. A. Female. B. Male. The kidneys are set apart.

Female Reproductive Organs. The *ovaries* are also paired and elongated bodies (Fig. 5.49A). The ovaries are typically like that of other fishes and are kept in position in Protopterus by *mesovarium* but in Neoceratodus these are attached with the dorsal body wall. The *oviducts* are located on the lateral side of the ovaries. Each oviduct (Mullerian duct) opens anteriorly into the body cavity by a fringed slit-like opening. The anterior part of the oviduct is greatly convoluted and the posterior part is slightly expanded to form the *uterus*. The uterii join posteriorly to form a median *vagina* which opens into the *urinogenital sinus*. In nonbreeding stage, the oviducts are nearly straight but in breeding season these become highly convoluted. The eggs are shed free into the body cavity and carried out by the oviducts.

DEVELOPMENT

The eggs are minute (measuring 3.5–4 mm in *Protopterus aethiopicus*) and shellless. In Lepidosiren the first three cleavage planes are vertical (Fig. 5.50) and are restricted to the animal pole which subsequently extend around the vegital pole. Gradually the egg is divided into cells. The cells on the vegital side are larger in size and contain yolk (megameres) and that on the animal end are smaller (micromeres). A blastula is produced which contains a *blastocoel* inside. During the onset of gastrulation, the megameres invaginate through the blastopore and the micromeres spread over the entire embryo. The gastrula elongates, neural folds are produced and the developing embryo transforms into the larva. Each larva after hatching, attaches itself to the substrata by the ventral sucker. The larva is a nonfeeding form and derives the nutrition from the yolk. In lungfishes the egg contains limited quantity of yolk, as a result fully-formed larva is very small. Four pairs of external gills are visible in the larvae of Protopterus and Lepidosiren, while in Neoceratodus the opercular folds develop prior to the formation of the external gills. The external gills degenerate with the development of the lung. Vestiges of the external gills may persist in adult stage. The lungs in the dipnoans, like that of other tetrapods, develop as an outgrowth from the floor of the pharynx which becomes eventually shifted to the dorsal side of the gut. In Protopterus and Lepidosiren a peculiar structure of unknown function called the *Pinku's organ* is present. This structure is derived from the spiracular rudiment. Development of such a structure is not found in Neoceratodus.

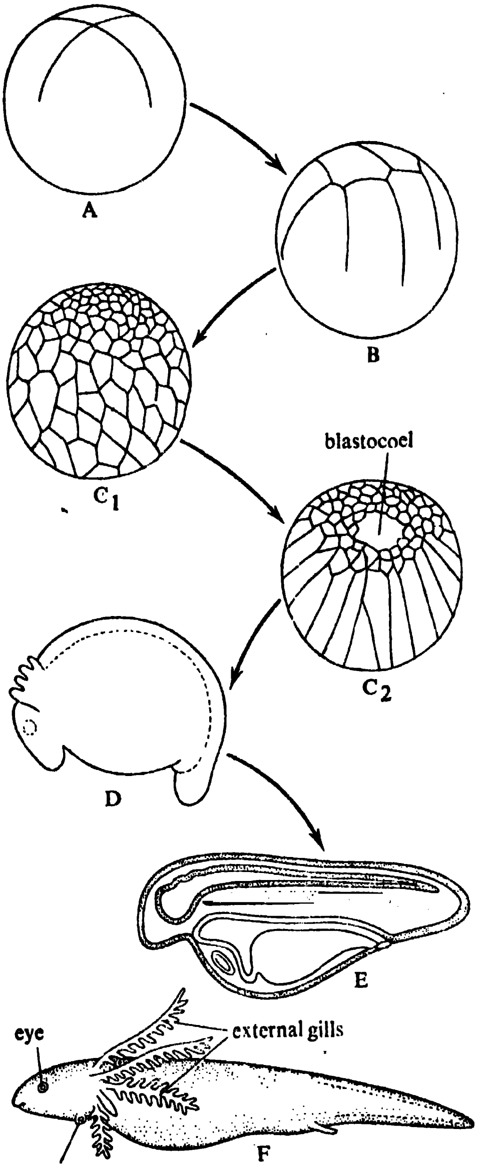


Fig. 5.50. Development of *Lepidosiren*. (A) Four-celled stage. (B) Showing the third cleavage. (C$_1$) An intact blastula. (C$_2$) Sectional view of blastula. D. Early larva. E. Longitudinal sectional view of a late larva. F. A late larva showing the external gills.

Three genera of the living lungfishes, Protopterus, Lepidosiren and Neoceratodus have similar structural construction. These forms differ in minor points which are primarily due to the different modes of adaptations. The differences existing between them are tabulated in Table Chordata– 5.

AFFINITIES

From the anatomical standpoint, the dipnoans form a sort of structural bridge between the fishes and the amphibians. Like that of other fishes, the dipnoans possess gills and spend life in water. But unlike fishes, the lungfishes can survive long dry spells by respiring through the air-breathing lungs like that of amphibia. The paired fins are also used much the same ways the amphibians employ their limbs. Because of this fact many workers postulate that the dipnoans hold the ancestry of the amphibia. Before going into the details of the phylogenetic consideration, the affinities with the different group of fishes and with the amphibia are considered first.

RELATIONSHIP WITH FISHES (IN GENERAL). The lungfishes show close similarity with the fishes and their piscine affinity is well established. The characteristics by which the lungfishes resemble with the fishes are: (1) The notochord is persistent. (2) The vertebrae lack centra. (3) The skull shows little ossification with many investing bones. (4) Four to six branchial arches are present. (5) The dermal fin-rays are slender and are largely ossified. (6) The body is covered by overlapping cycloid scales. (7) The tail fin is diphycercal. (8) The gills constitute the respiratory organs to absorb the oxygen which remains dissolved in water. (9) The lateral line sense organs are present. But the relative position of the lungfishes amongst the bony fishes is controversial because they bear many primitive features by which they resemble the elasmobranchs.

RELATIONSHIP WITH ELASMOBRANCHS. The lungfishes resemble the elasmobranchs by having (1) similar conus arteriorsus, (2) spiral valve in the intestine, (3) similar construction of the female reproductive system, (4) identical diencephalon and (5) no nephrostome in the kidney tubules. These similarities speak about the primitiveness of the dipnoans.

RELATIONSHIP WITH OSTEICHTHYES. The lungfishes and ray-finned bony fishes are included under the class Osteichthyes. But as regards the intraclass affinities of the group, the relationship with the subclass Crosspterygii is quite close. The lungfishes resemble with the subclass Actinopterygii by having: (1) Similar lobate paired fins. (2) Presence of cosmine covering the cycloid scales and skull bones in Dipterus. (3) Paired inferior jugular veins are present. (4) Presence of powerful palatine and splenial teeth. (5) Presence of blunt snout with ventral nostril. (6) Presence of swim bladder, although modified into 'lungs' in dipnoans. (7) Presence of operculum. But the similarities with other crossopterygians are very close. The common features are: (1) Presence of internal nostrils. (2) The tail fin is diphycercal.

TABLE CHORDATA—5

FEATURES	PROTOPTERUS	LEPIDOSIREN	NEOCERATODUS
1. Distribution	Tropical Africa.	Tropical South America.	Australia.
2. Habitat	Inhabits the river and large lakes. It aestivates when the river becomes completely dried up in summer.	Like Protopterus, Lepidosiren also aestivates during summer.	It lives in river which becomes shallow in summer, but never dried up completely. It lives in that toxic water by adopting aerial respiration. Aestivation is absent. The lungs work in conjunction with the gills.
3. Feeding habit	Carnivorous and eats the worms, crustaceans, insects, frogs and many other animals. Sometimes this fish attacks the same species.	Mostly carnivorous and sometimes feeds on plant materials. It is not exclusively carnivorous.	Carnivorous fish which devours molluscs, crustaceans and various worms.
4. Length	1.80–2.10 m in length.	1.20 m in length,	1.50 m in length.
5. Paired appendages	Elongated and slender with extremely reduced radials.	Like that of Protopterus.	Broad and leaf-like with highly developed radials.
6. Eyes	Smaller and ill-developed.	Moderate size and well-developed.	Like that of Lepidosiren.
7. Skull	The skull lacks fontanelles.	Frontanelles are present.	Frontanelles are absent.
8. Lower jaw	True splenial and dentaries are present.	True splenials and dentaries are present.	The splenials and dentries are vestigial.
9. Lungs	Two lungs are present.	Two lungs are present.	Only one lung is present which is possibly due to the suppression of the original left lobe.
10. Hyoidean gill	Is a hemibranch.	A hemibranch like that of Protopterus.	Is a pseudobranch which is supplied by an artery from the first efferent branch.
11. External gills and sucker	Four pairs of external gills and suckers are present in the larva. Vestiges of these external larval gills may persist in the adult.	Four pairs of external gills and suckers exist in the larva which are totally absent in the adult.	As the operculum develop earlier than the formation of the gills, external gills are absent in the larval stage.
12. Accessory respiratory organ	The gills and the lungs are the main respiratory structures. No accessory respiratory structure is developed.	During breeding season, vascular filaments are developed in the pelvic fins of male which serve as the accessory respiratory structure besides the gills and lungs.	No accessory respiratory organ is present.
13. Abdominal vein	Absent.	Absent.	An abdominal vein is present which originates from the union of the pelvic veins.

TABLE CHORDATA—5 (*contd.*)

FEATURES	PROTOPTERUS	LEPIDOSIREN	NEOCERATODUS
14. Conus arteriosus	A spiral valve and three rows of proximal valves are present.	Exactly similar to that of Protopterus.	The conus arteriosus lacks the spiral valve. Both the distal and proximal rows of valves are present.
15. Optic lobes	Unpaired.	Unpaired.	Slightly separated and form paired lobes.
16. Lateral line sense organs	The sense organs are lodged in grooves.	The sense organs are placed inside the canals in the skin.	Similar to that of Lepidosiren.
17. Kidneys	Extremely elongated bodies and the posterior ends are fused with each other.	Like that of Protopterus but the posterior ends remain separate.	Similar to that of Protopterus, but the kidneys are not so elongated.
18. Ureter	Two ureters, one from each kidney, remain separate.	Like that of Protopterus.	Two ureters may unite before opening into the cloaca.
19. Testes	The testes are elongated narrow bodies and round in cross-section.	Similar to that of Protopterus, but extremely elongated extending the entire length of the body cavity.	The testes are thick and triangular in cross-section.
20. Sexual dimorphism	Absent.	Present during breeding season when the males develop vascular filaments in the pelvic fins.	Absent.
21. Pinku's organ	Present.	Present.	Absent.

(3) Existence of cosmine covering the scales. (4) Similar skull bones. (5) Presence of swim bladder functioning as the lung. (6) The intestine contains spiral valves. (7) The conus arteriorsus is contractile. (8) External gills are present in the larvae. Such a close similarity existing between the groups suggest the contention that the lungfishes are phylogenetically related with the other crossopterygians.

RELATIONSHIP WITH AMPHIBIA. The lungfishes resemble the amphibians by many characteristics. The common features are: (1) The presence of vomerine teeth. (2) The lungs are capable of pulmonary respiration. A pulmonary artery and a pulmonary vein are present. (3) The circulatory system of dipnoans resembles that of amphibian by many points, viz., the spirally twisted conus arteriosus is divided into two by a longitudinal partition. The auricle and the sinus venosus are imperfectly divided into two parts. The pericardium is thin walled. The ventral aorta is short. Similar inferior vena câva and the presence of anterior abdominal vein. (4) The skin glands are multicellular. (5) Presence of dermal scales in Gymnophiona. (6) The brain of the lungfishes resembles that of amphibia specially in the structure of the cerebrum and cerebellum. (7) The spermatozoa are carried through the excretory part of the mesonephros. (8) The structure of egg and the development are similar. (9) The larvae of Lepidosiren and Protopterus possess the external gills and sucker. In some species of Protopterus external gills may be persistent. (10) The jaw suspension is autostylic.

Although the dipnoans resemble the amphibians by a number of features, there are many individual specialised characteristics by which they are separated from the amphibians. These are: (1) The skull is largely cartilaginous with little ossification. (2) The maxillae and premaxillae are absent. (3) Some anterior vertebrae become fused with the skull. (4) Presence of characteristic tooth plates. (5) The lungs are located dorsal to the gut. The common characteristics present in the lungfishes and amphibians are due to their evolutionary convergence and are possibly resulted as the adaptive modifications to a similar environmental condition.

The lungfishes possess real lungs and Neoceratodus even 'walks' across the muddy bottoms of the river by using the paired fins like the 'legs'. This fact tempts one to think that these fishes have some direct connection with the forms which led to the origin of land vertebrates. From the anatomical standpoint, the dipnoans exhibit close similarities with the bony fishes, specially with the rhipiditians in one hand and the amphibians on the other. This transitional status of the dipnoans makes this group of fishes interesting. The contention of holding the direct ancestry of the land vertebrates is proved to be untrue now-a-days. But their relation with the ancestral stock of the land vertebrates is supported by numerous evidences. The dipnoans, although survive by only three genera live in widely separated parts of the earth, have left behind a complete geological succession of the extinct dipnoans leading to the modern forms. All the dipnoans are united under a common order by a number of characteristics. These features are: (1) The presence of internal nostrils. (2) The scales and bones are covered by cosmine. (3) The autostylic mode of jaw suspension. (4) The peculiar pattern of teeth. Presence of these features also testify the biological truth that the lungfishes have evolved from a common ancestor with the other crossopterygians. The earliest known fossil dipnoan is represented by the genus, *Dipterus* (*Dipnorhynchus* is supposed by many to be more primitive than Dipterus). Dipterus possesses the following primitive features: (1) The body is covered by stout cosmine covered cycloid scales. (2) Two small dorsal fins are present. (3) The tail fin is of heterocercal type with a small epichordal lobe. (4) Numerous conical teeth are present. During the course of evolution the following changes have been undergone to become the modern lungfishes: (1) Fusion of median fins to form a continuous one. (2) Reduction in the number of dermal plates in the skull. (3) Change over from the heterocercal to diphycercal tail. (4) Fusion of the conical teeth to form characteristic tooth-plates with ridges. (5) Reduction in the number of opercular bones. Dipterus is fundamentally akin to the most primitive crossopterygian, *Osteolepis*. The scales and the head bones of Dipterus are strikingly similar to that of the contemporary crossopterygians. The semblances in some cases are so close, their relative position within the subclass becomes sometimes confusing.

The amphibians have evolved from the crossopterygian ancestor. This particular aspect is dealt in details in the Chapter—6. The crossopterygians are represented by two groups, the rhipidistians and the dipnoans. Although both the groups are on the verge of their racial passing, they give us an insight of the emergence of the land vertebrates. A survey of their past geological history suggests that the rhipidistian line and the dipnoan line converge back as we follow them further backward. This is evidenced by the presence of close similarity in the earlier representatives of both the above groups. The dipnoans constitute a very primitive race and possess many primitive characters in comparison to the then crossopterygians. This primitive organisation nullifies the concept of derivation of the dipnoans from the rhibidistian stock However, both the groups after emerging from a common ancestral stock become diverged widely in course of time and space.

The phylogenetic significance of the dipnoans as regards the holding of the direct ancestry of the amphibian is questionable. Because this view is confronted with serious anatomical difficulties which become difficult to interprete. The most important obstacle is the derivation the terrestrial limb from the peculiar and specialised archipterygial paired appendages of the dipnoans. The development of cloacal bladder is different. In the dipnoan, the cloacal bladder develops from the dorsal wall of the cloaca but in amphibians it develops from the ventral wall. The rhipidistians, on the other hand, present fewer of such obstacles. The earliest fossil amphibians show deeper similarities with *Osteolepis* (primitive rhipidistian) of Devonian period than any extinct and surviving dipnoans (Fig. 5.51). It is universally accepted that the amphibians have originated either directly from some rhipidistians or from an unknown group closely related to the rhipidistians but never from the dipnoan source. It can best be suggested that the dipnoans have diverged very early from the remote basic stock from which the amphibians actually originated. The rhipidistians and the dipnoans are the divergent offshoots of a common piscine ancestral stock. If the contention of the emergence of the amphibians from the rhipidistian forms be taken as a fact, the dipnoans can be regarded as the 'granduncle' of the land-dwellers but not the 'grandfather'. Besides all these complications regarding the phylogeny of the land dwellers, the modern dipnoans give us a glimpse of the conditions that have caused the vertebrates to conquer the land and the possible ways how the difficulties have been solved by structural adaptations.

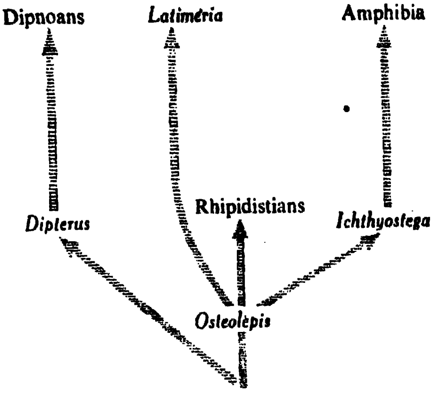


Fig. 5.51. Schematic phylogenetic tree showing the relationship of the dipnoans with the amphibians and *Latimeria*.

SOME INTERESTING FISHES

Fishes are notable for their wide diversities of form. Some important and peculiar fishes are described below:

Coccosteus. Coccosteus is the typical representative of the subclass Arthrodira and falls under the family Coccosteidae. It ranges from the middle to upper Devonian period. It is a swift predatory form measuring about 60 cm in length. It possesses all the typical characteristics of the subclass and in addition, shows a few individual diagnostic features. It has a fish-like body with a distinct head and a thoracic region. Both these regions are heavily armoured. The posterior end of the body is usually naked. The head is movably attached with the thoracic region by a ball and socket arrangement. The tail is heterocercal. The large eyes are protected by bony rim. The movable lower jaw is attached with the skull directly and is composed of a single bony piece.

Cetorhinus. Cetorhinus is a peculiar shark under the Pleurotremata. It is commonly known as the basking shark (Fig. 5.52A). It is not predaceous in habit.

It collects its food by straining small planktonic forms by the special comblike structures produced by the gill rakers. By this feature, it resembles with the whale bone of Cetaceans. Numerous small eggs are produced which develop within an 'uterus'. Although the development is intrauterine, no placenta is formed.

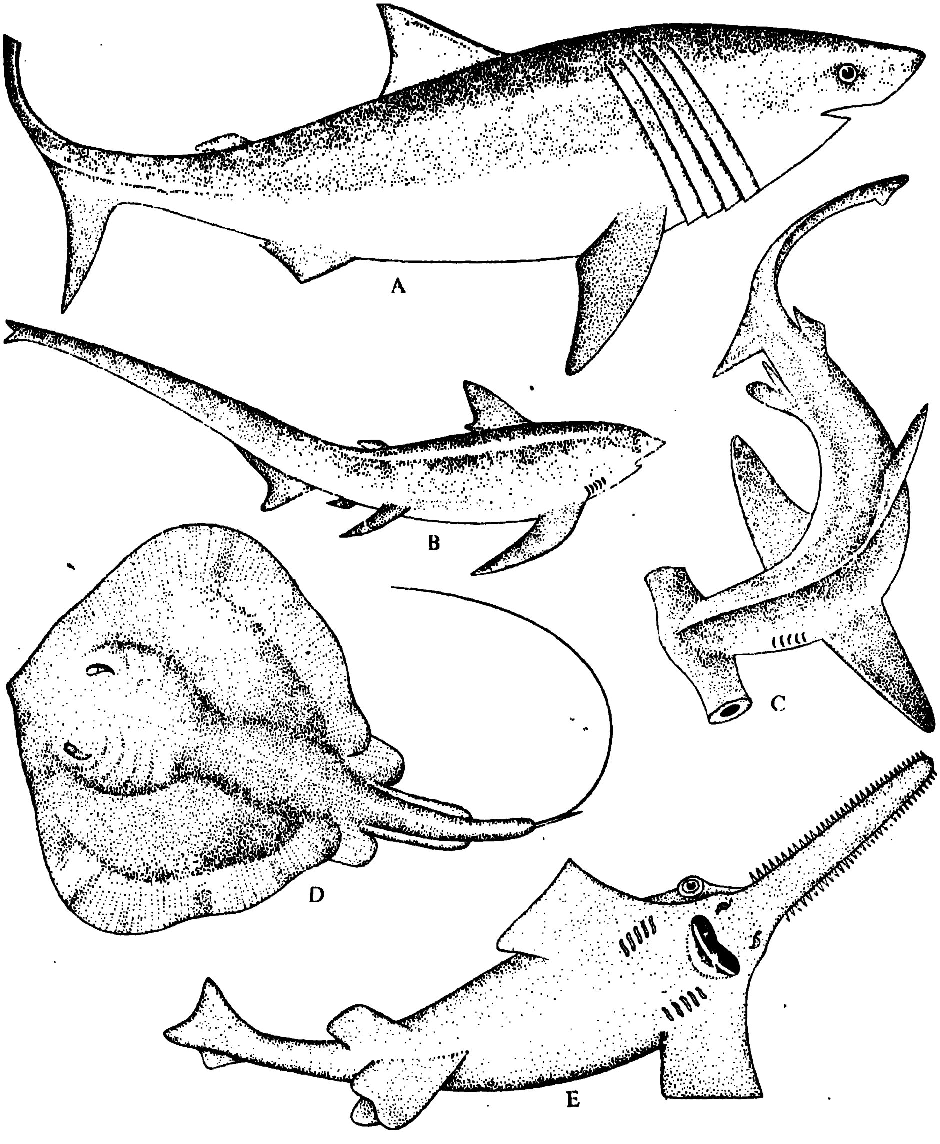


Fig. 5.52. Some peculiar cartilaginous fishes. A. Basking Shark (*Cetorhinus*). B. Thresher Shark (*Alopias*). C. Hammer head Shark (*Sphyrna*). D. Sting Ray (*Trygon*). E. Saw fish (*Pristis*).

Hexanchus. Hexanchus is the most primitive living shark under the suborder Pleurotremata. Another related genus, *Heptranchias* has the similar body construction like Hexanchus except the number of gill-slits. Heptranchias possesses seven pairs of gill-clefts while Hexanchus has six pairs. The body is elongated with an unconstricted notochord. It inhabits the warm water and moves slowly. It has an amphistylic jaw suspension. It is viviparous but development occurs without the formation of placenta.

Pristis. Pristis (or the saw fish) is a specialised representative of the Hypotremata. The most common saw fishes of the Indian coast are: *Pristis cuspidatus* and *Pristis microdon*. The body is elongated and becomes slightly broadened laterally. The rostrum is drawn out into a blade armed with two lateral rows of knife-like denticles (Fig. 5.52E). The length of the 'saw' equals the length of the one-third part of the body. The head strikes from side to side among the shoals of fishes and may also give slashing blows to its enemies. The saw fishes may attack the soft parts of the whale and tear off pieces of flesh by their 'saws'. There are a few species under this genus which inhabit the fresh water. The saw fishes are abundant in India, China and the Gulf of Mexico. The saw fishes may reach a length of about 3-6 m. The saw fishes are viviparous.

Raja. Raja (or common skate) is a specialised bottom-living Hypotremata having a dorsoventrally flattened body. The anterior part of the body, specially the pectoral fin region, becomes laterally extended. The posterior part of the body gradually thins out into a whip-like tail. The body of Raja is perfectly rhomboidal in shape. The median fin is greatly reduced. The mouth is armed with many sharp teeth to catch the fishes and crustaceans. Several species of *Raja* possess week electric organs.

Raja uses the pectoral fins as the propellers during swimming like "water-wings". Some species under this genus are protectively coloured on the top and below. There is a pattern of white and black marks on the dorsal side which help to break up the outline of the body. The mode of catching the prey is peculiar by dropping down over the prey with its broad body and fins.

Trygon. Trygon (or sting ray) has a similar body plan as in Raja excepting a few individual characteristics. The tail is modified in a lashing sting (Fig. 5.52D). The dorsal fin persists as a poisonous spine.

Rhinobatis. Rhinobatis (or banjo-ray) is a member of the Hypotremata which has existed since Jurassic to the recent times. The fins remain separate, i.e., the edges of the fins are free. The tail is well-formed. The pectoral fins are greatly enlarged.

Squatina. Squatina (or Angel shark) is a bottom-living Pleurotremata under the division Squaloidea. It bears a superficial similarity with the skates and rays. Squatina represents a transitional stage between the typical sharks and the skates and rays. The body is short and broad. The pectoral and pelvic fins are expanded laterally to form wing-like expansions that gave the name of the fish.

Sphyrna. Sphyrna (or the Hammer-headed shark) is characterised by having a laterally flattened head (Fig. 5.52C). The head is prolonged laterally into two large lobes. These lobes are provided with cartilaginous support from the nasal part of the skull. The head, thus, assumes the shape of a hammer. The eyes are situated at the tip of the lateral projections of the head. The hammer-headed sharks are very ferocious in nature. These sharks are used for extracting liver oil. They may attain the length of about 4.5 m. The common Hammer-headed shark of Indian coast is *Sphyrna zygaena*.

Alopias. Alopias (or the thresher shark) is a member of the division Squaloidea under Pleurotremata. It has a peculiar method of seizing the prey (Fig. 5.52B). The tail is extremely elongated and powerful. The tail has almost the same length as that of the rest of the body. During hunting, several sharks hunt together and use their whip-like tails to drive the small fishes into groups when they can then be easily eaten. In isolated cases, a thresher shark is able to kill the prey by the powerful lashing of its tail.

Torpedo. Torpedo (or the electric ray) is a curious animal under the suborder Hypotremata. ***Torpedo marmorata*** is the most common electric ray of Indian seas. The fins are extended anteriorly so that the body assumes nearly a circular outline. A pair of electric organs is present one on each dorsal side of the body (See Fig. 5.69). The electric organs are formed by the specialisation of the lateral plate muscles situated between the pectoral fins. The electric organs are innervated by cranial nerves.. These are defensive organs and are capable of giving a heavy electric shock.

Myliobatis. Myliobatis (or the eagle ray) has specialised body for its bottom-living habit. The pectoral fins become greatly expanded to give the body considerably wider along the transverse plane than its length. The width of the body reaches about six metres. Sometimes eagle ray catches the prey by its 'wings' and is also called the "sea vampire"

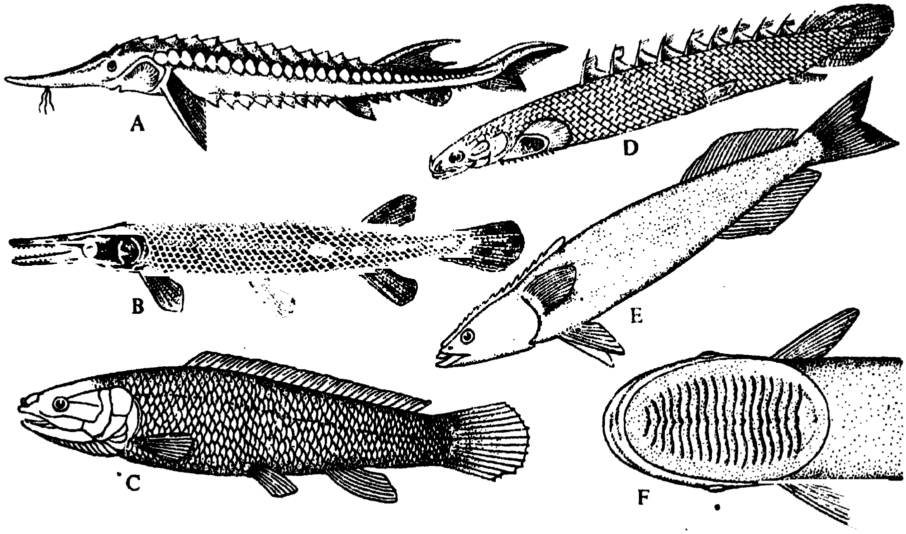


Fig. 5.53. Some interesting bony fishes. A. Sturgeon (*Acipenser*). B. Gar fish (*Lepisosteus*). C. Bow fin (*Amia*). D. Bichir (*Polypterus*). E. Sucker fish (*Echeneis*). F. Enlarged dorsal view of the head to show the sucker. Note that the sucker is an oval disc with transversely arranged furrows.

The teeth become flattened to grind the molluscan shells.

Echeneis. The sucker fishes or remoras (Fig. 5.53E) are peculiar bony fishes found in all seas. *Echeneis* is the typical genus of the group. The related genera are: *Phtheirichthyes*, *Remora*, *Remilega*, *Rhombochirus*. The size of the fishes reaches upto 53 cm. The anterior dorsal fin is transformed into an oval adhesive vacuum disc. This disc is flat and is surrounded by membranous margin. It is transversely furrowed and situated on the upper surface of the head (Fig. 5.53F). The sucker fishes can attach themselves to the body of other fishes, turtles, whales or any other floating objects by producing numerous suction chambers and are thus carried from one place to the other. They leave the host periodically to capture small fishes. The adhering power of the adhesive disc of remoras is quite high and the sucker of a large individual can resist a vertical pull of about 40 pounds. The pelvic fins are provided with external spines and are thoracic in position. Other characteristic features are the absence of pseudobranch, swim bladder and fin-lets.

Lophius (Angler fish). This particular fish is also commonly called by the names, frog-fish, monk-fish, sea-devil, toad-fish and by many other names. The head and anterior portion of the body are greatly enlarged (Fig. 5.54C). The scales are absent. The dorsal fin is 'spinous' and is represented by a few isolated flexible rays. Of the rays, the first one is extremely elongated and situated on the head and bears a dilated bulb at the tip. *Lophius piscatorius* has a broad head with a huge mouth. The jaws are beset with numerous teeth. It attains a length of about 1.2 m. Many phosphorescent organs are present. The foremost long fin-ray bears a terminal bulb to attract the small prey. The terminal bulb is capable of rapid regeneration. The outline of the body is partially obliterated by stumpy dermal appendages which mimic the leaves of the aquatic weeds. The pectoral fins are broad and are capable to 'walk' on the ground in search of prey.

Hippocampus. The peculiar marine fish is called the 'sea-horse', because it bears a superficial resemblance with the head of horse (Fig. 5.55B). The toothless mouth is suctorial and the snout is tubular. The head is large and is present at right angle to its body. The skin is covered by bony plates. The gills are composed of many small rounded lobes attached to the gill-arches (Fig. 5.55C). Such gills are called the lophobranchs. The operculum is a large plate-like structure. The musculature is feebly developed. It is a bad swimmer and usually carried passively by the currents. It can swim vertically with the help of the dorsal fin. The caudal fin is absent and the tail is prehensile. The male individual is characterised by having brood pouch at base of the tail where the eggs are housed until hatching. The other sea-horses are: *Gastrotikeus*, *Solenognathus*, *Phyllopteryx*, etc.

Syngnathus. This genus is found in all warm seas and is called the greater pipe-fish (Fig. 5.55D). The body of the fish is slender with very small fins. The scales are transformed into ring-like plates covering the body. The gills are lophobranchs and the gill-openings are minute. The dorsal fin is soft and the pelvic fins are absent. Like that of *Hippocampus*, the snout is tubular with suctorial toothless mouth. The males possess broad pouch where the eggs are stored (Fig. 5.55E). The tail is nonprehensile with small caudal fin. Other genera of pipe-fishes are: *Siphonostoma*, *Doryichthys*, *Nerophis*, *Protocampus*, *Ichthyocampus*, *Stigmatophora*, etc.

Phycodurus. Phycodurus eques is the Sea dragon of Australian sea shores. It resembles Hippocampus very closely and exhibits excellent mimetic resemblance like a piece of sea-weed (Fig. 5.55A). The outline of the body is broken up by developing

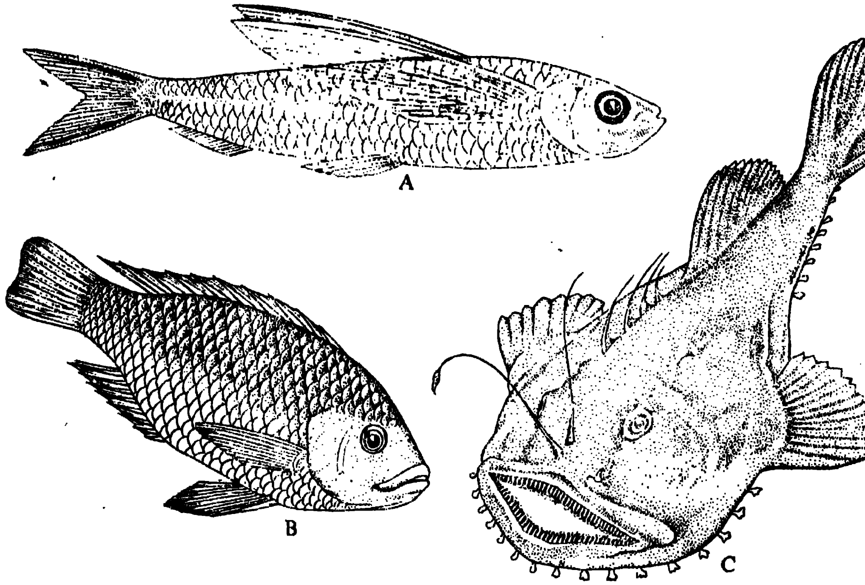


Fig. 5.54. Some interesting bony fishes (Contd.). A. Flying fish (*Exocoetus*). B. American Koi (*Tilapia*). C. Angler fish (*Lophius*).

numerous membranous leaf-like processes. The snout is tubular and the mouth is toothless. The gills are lophobranchs. The tail is prehensile and lacks caudal fin.

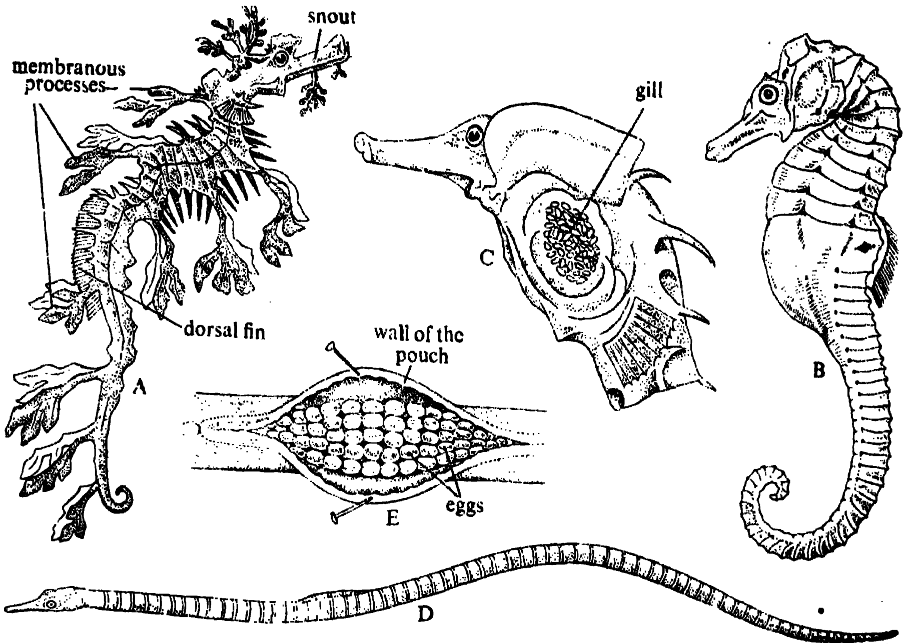


Fig. 5.55. Some interesting bony fishes (Contd.) A. Sea dragon (*Phycodurus*). B. A male sea-horse (*Hippocampus*). Note the presence of brood pouch. C. The operculum on the left side of *Hippocampus* is replaced to show the gills. Note that the gill filaments have assumed lobulated appearance. D. Pipe-fish (*Syngnathus*). E. The brood pouch of a male *Syngnathus* is opened to show the eggs.

Tilapia. Tilapia is a typical 'spiny-rayed' fish under the family Cichlidae (Fig. 5.54B). It is notable for its highly developed parental care. Most of the species under the genus *Tilapia* are mouth-brooders. In *Tilapia mossambica*, the eggs after fertilization, are taken up into the mouth cavity of the mother, where the eggs are brooded. Even after hatching, the youngs take shelter in the mother's mouth in times of danger. Tilapia, although popularly called the American Koi, is an African genus. *T. nilotica* is also a mouth-brooding form. The youngs of all the species of Tilapia possess a dark spot ("*Tilapia-mark*") near the posterior end of the dorsal fin which may disappear in adult. Tilapia can breed and multiply rapidly in pond. The rate of multiplication is quite high and their culture is not a problem.

Exocoetus. Exocoetus is a common flying fish (See Fig. 5.54A) of tropical and subtropical seas. The fishes usually live in groups. The body is covered by scales. The pelvic fins are devoid of spines and each bears six rays. The dorsal fin is situated above the anal fin. The pectoral fins become greatly elongated into parachute-like organs. Both the jaws are short. *Exocoetus volitans* can leave the water by a powerful tail movement and float rapidly through the air in a straight line by the activity of the expanded pectoral fins.

The related genera of Exocoetus are: *Cypselurus* (flying fish), *Belone* (gear-fish or gar-pipe or sword fish with no finlet and the jaws are elongated into a beak), *Hemirhamphus* (halfbeak with the lower jaw extended beyond the upper jaw.), *Scombersesox* (skipper or saury with a beak and finlets behind the anal and dorsal fins).

Acipenser (Sturgeon). Acipenser (See Fig. 5.53A) is a large sized fish living in the seas and rivers of Northern hemisphere. They feed on worms, molluscs, small fishes and aquatic plants. It has an elongated shark-like body. The snout is long. The mouth is small, toothless and ventrally located. Four barbels are present in front of the mouth. The body bears a few rows of bony scutes (modified ganoid scales). The tail fin is heterocercal. The stomach lacks the blind diverticulum. Presence of unconstricted notochord and loss of ossification in the whole skeleton are the most notable features.

The common sturgeons are: *Acipenser sturio* (common sturgeon), *A. transmontanus* (white pacific sturgeon), *A. fulvescens* (rock sturgeon), *Scaphirhynchus platorhynchus* (fresh water shovel-nosed sturgeon). *Polyodon* (spoonbill sturgeon of Mississippi), *Psephurus* (spoonbill sturgeon of China). Acipenser possesses spiracle, but Scaphirhynchus is without spiracle. Polyodon lacks bony scutes and barbels.

Polypterus (Bichir). Polypterus (See Fig. 5.53D) has a slender body covered by thick ganoid rhombic scales. The dorsal fin is divided into eight or more dorsal fin-lets ("Sails") each of which is preceded by a spine. The tail is arrow-shaped and diphycercal. The swim bladder is lung-like and is capable of breathing air. The larvae bear slender external gills. The conus arteriosus contains three longitudinal rows of valves, each row has got nine valves. One pair of gular plates is present between the rami of the lower jaw.

Polypterus bichir of tropical Africa attains a length of about 1 m. The other related genus, *Calamoichthys* (= *Erpetoichthys*) of the rivers of Nigeria and Congo has an elongated body devoid of pelvic fins.

Lepisosteus (Lepidosteus). *Lepidosteus* is a common fresh water gar-pike (Fig. 5.53B) of North and Central America. It has an elongated body covered over by thick ganoid rhombic scales. The scales of the trunk are arranged in oblique rows. The snout is much elongated. The vertebral column is bony. Lepisosteus possesses an admixture of primitive and advanced characters. The primitive features are: (1) the presence of a long valvular conus arteriosus, (2) absence of a bulbus arteriosus, (3) the walls of swim bladder are cellular, (4) semiheterocercal tail fin and (5) thick ganoid scales. The specialised features are: (1) the reduction of maxillae and their functional replacement by many tooth-bearing infraorbital structures, (2) opisthocoelous vertebrae composing the vertebral column and (3) the presence of numerous cheek plates. Loss of central jugal plate, absence of spiracles and presence of pyloric caeca are the individual characteristics. The gar-pikes are voracious eaters and prey on smaller fishes. *Lepisosteus tristaechus* attains a length of about 3 metres.

Amia (Bow-fin). *Amia calva* (Fig. 5.53C) is the solitary species of the family Ammidae and lives in the fresh water rivers and lakes of North America. It is a predatory fish and lives on small fishes. It has a fusiform body covered by overlapping cycloid scales. The dorsal fin is long and continuous. The tail fin is homocercal. A dorsal bilobed cellular swim bladder is present which helps in respiration. The spiral valve is present in the intestine. Presence of a small valvular conus arteriosus and one large jugal plate between the rami of the lower jaw are some of the primitive features. The vertebrae are solid and possess amphicoelous centra. The pyloric caeca are absent. The spiracles are also absent. Two comb-like structures are situated on the throat.

The male individuals are smaller than the females. The males are sharpely distinguishable from the female by having a shiny black spot on the basal part of the caudal fin. Before spawning the male prepares a saucer-shaped crude nest with aquatic plants. After the eggs being laid by the female in the nest, the male guards the nest uptil the hatching of the eggs.

Tetrodon. Tetrodon is commonly called the globe fish. The body is more or less globose in shape. During collection, it frequently produces a sound by forceful expulsion of air from the oesophagus. It can distend the body by swallowing air or water inside the inflated oesophagus. The scales are modified into spines which can be erected by cutaneous muscles. The teeth are fused to form beak which has a prominent median suture. The flesh is usually poisonous. *Tetrodon cutcutia* and *T. patoca* are the two typical Indian species. The related fishes are: *Diodon* (porcupine fish), having beak without median suture). *Mola mola* (Oceanic sunfish with leathery skin, enlarged anal and dorsal fins, short compressed body without tail.)

Amphipnous. Amphipnous is an eel-like fish. The dorsal and anal fins are devoid of fin-rays and are continuous with the caudal fin. Paired fins are absent. The gill-openings become confluent into one slit on the ventral side of the body. Lack of swim bladder and pyloric caeca is the characteristic features to note in the anatomy of this fish. *Amphipnous cuchia* (a common Indian fresh water eel) bears three gill arches, of which the second one bears the gills. A pneumatic sac is present on each dorsal side of the branchial chamber which acts as the 'lung' (See Fig. 5.61E). The other related genera are: *Monopterus* (with three gill arches and no pneumatic sac) and *Symbrachus* (with four gill-arches with large gills).

Heteropneustes. *Heteropneustes fossilis* is a common catfish under the family Siluidae (See Fig. 5.61C). It is called the Singhi fish and is notable for possessing an accessory respiratory air tube in addition to the gills. While living in water, it frequently comes to the surface to breathe atmospheric air. Heteropneustes has an elongated and slender body. The body is devoid of scales and grey in colour. The anterior vertebrae (second, third, fourth and sometimes fifth) become fused. The head is small and dorsoventrally flattened. The mouth is situated at the anterior end of the head. Four pairs of sensory barbels are present around the mouth. The maxillary bone is reduced and supports the barbels. A pair of eyes and a pair of nostrils are present. It resembles Clarias in basic structural organisation, but the dorsal fin is very small in comparison to the continuous extended dorsal fin of Clarias. In 'Singhi', the pectoral fins are located one on each side of the trunk just posterior to the opercular opening. Each pectoral fin is supported by nine rays, of which the first one is modified into a large sharpely pointed serrated defensive spine. The pelvic fins are comparatively smaller and each bears six fin-rays. The caudal fin is rounded and the anal fin is continuous with a variable number of fin-rays.

Clarias. *Clarias batrachus* is another air-breathing fish under the family Siluridae (See Fig. 5.61A). This is commonly called Magur fish. It has an elongated stout body with a broad head than 'Singhi' fish. The mouth is present subterminally. There are four pairs of sensory barbels around the snout. Of the four pairs, one pair is longer and stout while the rest three pairs are smaller. The maxillary bone is reduced and supports the barbels. Some of the anterior vertebrae are reduced. The accessory air-breathing respiratory organs are called the suprabranchial organs located dorsal to the gills. The fins differ slightly from that of Singhi fish. The dorsal fin is very large and extends along the entire middorsal side of the body and tail. It is supported by numerous fin-rays. The anal fin is present on the midventral line of the tail and is supported by numerous fin-rays. The tail fin is well-developed and is round. The pectoral fins are situated near the opercular openings. The first fin-ray in each pectoral fin is transformed into a sharply pointed defensive spine. The pelvic fins are supported by soft fin-rays and are placed on the ventral side near the pectoral fins.

Anabas. *Anabas testudineus* is popularly called the Koi fish (See Fig. 5.61B). It possesses well-developed accessory air-breathing structures and is capable of utilising oxygen present in atmospheric air. Anabas makes short excursion overland for a considerable period of time. It has a laterally flattened body with a prominent triangular head. The mouth is broad. The outer margin of the operculum is provided with opercular spines which aid in locomotion on land.

The fins are well-developed. The dorsal fin is composed of two portions, the anterior part is larger and supported by stiff spinous fin-rays while the posterior part is supported by soft fin-rays. The ventral fin is divided into two parts exactly like the dorsal fin. The tail fin is round and numerous fin-rays support the fin. The pectoral fins are located near the opercular openings. The basal, supporting the fin, is narrow while the terminal end is broad and semicircular. The pelvic fins are placed midventrally close to the pectoral fin.

CLASSIFICATION

CLASSIFICATION IN OUTLINE

Class **Placodermi** (or **Aphetohyoidea**)

- *Subclass* (I) Acanthodii e.g., *Climatius, Acanthodes, Diplacanthus.*
- *Subclass* (II) Arthrodira e.g., *Coccosteus, Dinichthyes, Titanichthys.*
- *Subclass* (III) Petalichthyida e.g., *Lunaspis, Macropetalichthys.*
- *Subclass* (IV) Antiarchi (or Pterichthyomorphi) e.g., *Bothriolepis, Pterichthyes, Ceraspis.*
- *Subclass* (V) Rhenanida e.g., *Gemuendina, Jagorina, Asterosteus.*
- *Subclass* (VI) Palaeospondylia e.g., *Palaeospondylus.*

Class **Chondrichthyes** (or **Elasmobranchii**)

- *Subclass* (I) Selachii
  - Order 1. *Cladoselachii* (or *Pleuropterygii*) e.g., *Cladoselache, Cladosus* and *Goodrichia.*
  - Order 2. *Pleuracanthodii* (or *Ichthyotomi*) e.g., *Pleurocanthus.*
  - Order 3. *Protoselachii* e.g., *Heterodontus* and *Hybodus.*
  - Order 4. *Euselachii*
    - Suborder A. Pleurotremata
      - Division a. Notidanoidea e.g., *Chlamydoselache* and *Hexanchus.*
      - Division b. Galeoidea e.g., *Carcharodon, Scyliorhinus* and *Mustelus.*
      - Division c. Squaloidea e.g., *Squalus, Squatina* and *Alopias.*
    - Suborder B. Hypotremata e.g., *Raja, Rhinobatis, Torpedo, Pristis, Dasyatis, Aetobatus.*
- *Subclass* (II) Bradyodonti
  - Order 1. *Eubradyodonti* e.g., *Helodus* and *Psammodus.*
  - Order 2. *Holocephali* e.g., *Chimaera* and *Harriotta.*

Class **Osteichthyes**

- *Subclass* (I) Actinopterygii
  - Super order (1) Chondrostei.
    - Order 1. *Palaeoniscoidea* e.g., *Cheirolepis, Palaeoniscus.*
    - Order 2. *Acipenseroidei* e.g., *Acipenser, Chondrosteus, Polyodon.*
    - Order 3. *Polypterini* (or *Cladistia*) e.g., *Polypterus, Erpetoichthys.*
  - Super order (2) Holostei.
    - Order 1. *Semionotoidea* e.g., *Lepisosteus* (or *Lepidosteus*).
    - Order 2. *Amioidea* e.g., *Amia.*
    - Order 3. *Pycnodontoidea* e.g., *Gyrodus, Pycnodus.*
    - Order 4. *Aspidorhynchoidea* e.g., *Aspidorhynchus.*
    - Order 5. *Pholidophroidea* e.g., *Pholidopleurus.*
  - Super order (3) Teleostei.
    - Order 1. *Isospondyli* (or *Clupeiformes*) e.g., *Salmo, Clupea, Hilsa, Notopterus.*
    - Order 2. *Haplomi* e.g., *Esox.*
    - Order 3. *Iniomi* (or *Scopeliformes*) e.g., *Myctophum, Synodus, Harpodon.*
    - Order 4. *Miripinnati* e.g., *Miripinna.*
    - Order 5. *Giganturoidea* (or *Giganturiformes*) e.g., *Gigantura.*
    - Order 6. *Lyomeri* (or *Saccophyngiformes*) e.g., *Saccopharynx.*
    - Order 7. *Ostariophysi* (or *Cypriniformes*) e.g., *Cyprinus, Electrophorus, Carassius, Catla, Labeo, Cirrhina.*
    - Order 8. *Apodes* (or *Anguilliformes*) e.g., *Auguilla, Muraena.*
    - Order 9. *Heteromi* (or *Halosauriformes* or *Notocanthiformes*) e.g., *Notocanthus.*
    - Order 10. *Synentognathi* (or *Beloniformes*) e.g., *Exocoetus, Belone, Cypselurus, Hemirhamphus.*
    - Order 11. *Salmopercae* (or *Percopsiformes*) e.g., *Percopsis, Columbia.*
    - Order 12. *Microcyprini* (or *Cyprinodontiformes*) e.g., *Typhlichthyes, Cyprinodon, Gambusia.*
    - Order 13. *Solenichthyes* (or *Syngnathiformes*) e.g., *Trachyrhamphus, Syngnathus, Hippocampus.*
    - Order 14. *Anacanthini* (or *Gadiformes* or *Macruriformes*) e.g., *Gadus, Lota, Merluccius.*

Order 15. *Allotrignathi* (or *Lampridiformes*) e.g., *Lampris*, *Trachypterus*, *Regalecus*.
Order 16. *Berycomorphi* (or *Beryciformes*) e.g., *Holocentrus*.
Order 17. *Zeomorphi* (or *Zeiformes*) e.g., *Zeus*.
Order 18. *Percomorphi* (or *Perciformes*) e.g., *Lates*, *Scomber*, *Perca*, *Micropterus*, *Tilapia*, *Kanagurta*, *Anabas*.
Order 19. *Gobimorphi* e.g., *Gobius*, *Periophthalmus*, *Boleophthalmus*.
Order 20. *Scleroparei* e.g., *Sebastes*, *Cottus*, *Gasterosteus*.
Order 21. *Thoracostei* (or *Gasterosteiformes*) e.g., *Gasterosteus*.
Order 22. *Hypostomides* (or *Pegasiformes*) e.g., *Pegasus*.
Order 23. *Heterosomata* (or *Pleurnectiformes*) e.g., *Solea*, *Psettodes*, *Cynaglossus*.
Order 24. *Discocephali* (or *Echeniformes*) e.g., *Remora*, *Echeneis*.
Order 25. *Plectognathi* (or *Tetrodontiformes*) e.g., *Balistes*, *Diodon*, *Mola*, *Tetrodon*.
Order 26. *Malacichthyes* (or *Icosteiformes*) e.g., *Icosteus*.
Order 27. *Xenopterygii* (or *Gobicsociformes*) e.g., *Gobiesox*.
Order 28. *Haplodoci* (or *Batrachoidiformes*) e.g., *Porichthys*, *Opsamus*.
Order 29. *Pediculati* (or *Lophiiformes*) e.g., *Antennarius*.
Order 30. *Opisthomi* (or *Mastacembeliformes*) e.g., *Mastacembelus*, *Macroquathus*.
Order 31. *Synbranchii* (or *Symbranchiformes*) e.g., *Symbranchus*, *Amphipnous*.
Order 32. *Channiformes* e.g., *Channa*.

Subclass (II) Crossopterygii

Order 1. *Rhipidistia*

Suborder 1. Osteolepidoti e.g., *Osteolepis*, *Megalichthyes*.

Suborder 2. Coelacanthini (or Actinistia) e.g., *Caelacanthus*, *Latimeria*.

Order 2. *Dipnoi* (or *Dipneusti* or *Dipneunomes*).

Suborder 1. Monopneumona e.g., *Neoceratodus*.

Suborder 2. Dipneumona e.g., *Protopterus*, *Lepidosiren*.

CLASSIFICATION WITH CHARACTERS

The classification of the fishes is really a very difficult task. Diverse opinions exist on this particular issue. The older idea of grouping all the fishes under one superclass, Pisces is no longer retained in the modern times. All the fishes are conveniently placed under three classes, Placodermi, Chondrichthyes and Osteichthyes. But the scheme of dividing the three classes into smaller groups is really puzzling. The scheme of classification followed in the present text is largely based on the principle adopted by Parker and Haswell.

Class I **Placodermi (or Aphetohyoidea)**

The earliest known jawed vertebrates are represented by a group of fossil fishes called the placoderms which appeared during the Silurian period. These fossil fishes exhibit many structural peculiarities and are included under the class Placodermi or Aphetohyoidea. The placoderms present wide range of adaptive radiation and flourish well in the Devonian and Carboniferous periods, but all of them became extinct by the end of the Permian. The placoderms possess many peculiar and specialised characteristics and are regarded to be the progenitors of the modern fishes. Although the placoderms form a heterogenous group of fishes, the following features characterise the class. The characteristics are: (1) The body is protected by heavy bony armour, a feature which has given the name 'placodermi' to the group. (2) The hyoid arch is unspecialised and does not take part in jaw suspension. The jaws are attached with the skull by their own processes. The peculiar type of jaw attachment is called the autostylic. This condition is also called the aphetohyoidean condition, because of this characteristic the placoderms are also called the Aphetohyoidea. This type of jaw attachment is regarded as the most primitive type of jaw suspension. (3) The spiracle is typically a gill-slit which is present anterior to the unmodified hyoid arch. (4) The paired fins are mostly present. The placoderms are divided into six subclasses.

Subclass I. Acanthodii

This subclass includes the most primitive placoderms. The members are smaller in size and are regarded as 'needle-finned sharks' because of their superficial semblance with the shark. The acanthodians were fresh water organisms and the geological history revealed their existence from the upper Silurian to the Permian with their maximum abundancy in the Devonian times. They have elongated fusiform bodies (almost eel-like) with a blunt snout. The eyes are large and are directed forward. The mouth is placed terminally. The tail is heterocercal. There are two dorsal fins in most cases, which may be reduced to one. A single anal fin is present. Series of paired fins are present between the pectoral and pelvic fins. These are quite numerous in primitive forms and become reduced to none in subsequent stages. Each fin is supported by a large spine along with the anterior edge of the fin. A well-formed pectoral girdle is present. Each half is composed of a scapula and coracoid which support the spines of the respective fins. Traces of basal elements are present in the pectoral fins.

The body is covered by small rhomboid scales. The scales are dermal derivatives and are essentially composed of bony material. On the head region, the scales become enlarged and form definite pattern of arrangement. The scales are comparable to the ganoid types. The neurocranium, jaws and branchial arches are mostly cartilaginous in nature. The jaws are primitive and have four ossified areas, two in the lower and two in the upper jaws. The upper jaw (palatoquadrate) is composed of two pieces and is toothless. The lower jaw is made up of mandible and possesses teeth. The teeth are modified scales. The hyoid arch is an unmodified branchial arch. The mandibular, hyoidal and all the branchial arches in primitive forms, are provided with small opercular folds. But in the higher forms the mandibular operculum becomes highly developed to cover all the gills.

The acanthodians, as stated earlier, hold the ancestry of many, if not, all of the gnathostomes. All the acanthodians are classified under six families—Brachyacanthidae, Diplacanthidae, Ischanacanthidae, Gyranthidae, Mesacanthidae and Acanthodidae. The first four families are characterised by having two dorsal spines and the rest two possess only one of such spines. Of the families, the Brachyacanthidae as examplified by *Climatius* represents the primitive forms. Examples: *Climatius, Acanthodes, Diplacanthus.*

Subclass II. Arthrodira (or Coccostei)

The members of this subclass are characterised by having strong cranial roof formed by the union of bony plates. These bony plates are sculptured by the presence of tubercles. The skull is articulated by a pair of condyles. The vertebrae lack centra but the neural and haemal arches are present. They are generally called the 'joint-necked' fishes and flourish well during the Devonian period. The posterior part of the body is prolonged into a whip-like tail which may or may not be covered by scales. An operculum covering the branchial arches is quite evident. The pectoral fins are greatly reduced and are represented by a pair of small unmovable lobed structures situated one on each side of the body. The pelvic fins are paired structures located on the ventral side. A well-formed dorsal fin is present.

The arthrodires are fast swimming and predatory forms. Some members of this group have attained large size. *Dinichthyes* and *Titanichthys* have recorded to be about 9 metres in length. The actual systematic status of the group is controversial. Although they are claimed to be related to the dipnoans and elasmobranchs, their close relationship with the acanthodians is well-established.

Examples: *Arctolepis, Coccosteus, Titanichthys, Dinichthys, Mylostoma, Rhamphodopsis.*

Subclass III. Petalichthyida

The members of this subclass resemble the subclass Arthrodira except the following points: (1) The orientation of the bony plates on the head is different. (2) The paired fins are constructed on different plan. (3) The ball-and-socket joint between the head and thorax is absent. (4) The pectoral girdle, pectoral fins and pelvic fins are Cladoselache-like. (5) The mouth is ventrally placed and the skull is dorsoventrally flattened like elasmobranchs. This suggests their bottom feeding habit. This subclass presents many structural similarities with the elasmobranchs, acanthodes and rhenanides. The examples are *Lunaspis* (lower Devonian) and *Macropetalichthys* (middle Devonian).

Subclass IV. Antiarchi (Pterichthyomorphi)

The members of this subclass are found in the Devonian period. They are fresh water forms and the fossils are well-preserved to reveal certain internal structures. The head and the thoracic region are provided with strong bony plates. The arrangement of the bony plates is strikingly similar to that of the subclass Arthrodira, but the mode of articulation of the head to the body is different. The tail is heterocercal with a ventral fold. The pelvic fins are usually absent. The intestine contains spiral valve. A pair of large sac-like lungs is present. The eyes are closely placed on the dorsal side of head. The mouth is ventrally placed. The jaws are poorly developed. The body is naked in some forms, but in *Pterichthys* the body and tail are covered with scales. Examples: *Pterichthys, Bothriolepis, Remigolepis, Microbrachius, Ceraspis, Asterolepis.*

Subclass V. Rhenanida

The subclass Rhenanida is represented by a group of Devonian placoderms resembling the modern rays. The body is flattened dorsoventrally with a broad head. The body is covered by small denticles which are attached to the bony plates. The bony plates constitute the body armour. The skull is fully ossified. The gills are covered by operculum. The spiracle is absent. The pectoral fins are large in size and are supported by the elongated radials. The pelvic fins are smaller and flattened. The dorsal fin is supported by anterior spine. A series of spines is present behind the dorsal fin. The pectoral girdle is devoid of lateral spine. The structural organisation of the subclass suggests that the members are adapted to bottom living. Examples: *Gemuendina, Asterosteus* and *Jogorina.*

Subclass VI. Palaeospondylia

This subclass is well represented by a single mid-Devonian representative, *Palaeospondylus* of Scotland. It has a dorsoventrally depressed skull and a well-ossified vertebral column. The vertebrae possess strong centra with well-formed neural arches and haemal spines on the posterior side. The auditory capsules are large in size—a feature resembling the agnathans. The tail is heterocercal. Traces of paired fins are present. The hyoid arch is complete but does not take part in jaw suspension. The external armour is completely absent. The structural plan of Palaeospondylus is very peculiar and presents many features resembling many other groups. The condition of the skull, particularly the floor, suggests larval condition. For this reason Palaeospondylus is regarded as the larva of a dipnoan or of Coccosteus or of an amphibian. The affinity of Palaeospondylus with the agnathans (specially with the hagfishes) was the consensus opinion for many years. The unclacified roof of the skull and the large auditory capsules suggest affinities with the agnathans. The presence of jaws has been shown in this fish, so the question of its inclusion with agnathans does not arise. Despite of all such affinities and lack of dermal armour, Moy-Thomas (1939) included Palaeospondylus under the class Placodermi in a separate subclass, because many typical placoderm features are present.

Class II **Chondrichthyes (Elasmobranchii)**

The class Chondrichthyes (Gr. *Chondros* =cartilage and *ichthys*=fish) includes a group of fishes known as the sharks, rays and chimaeras. The members of the class are also called the elasmobranchs which literally signify the 'plate-gilled' fishes. In spite of great morphological diversities, they form a very compact group characterised by possessing the following diagnostic characteristics: (1) They are mostly marine and predaceous forms. (2) The body is covered by tough skin containing minute placoid scales (denticles) and mucous glands. (3) There is no bone in the skeleton, i.e., the skeleton is cartilaginous in nature. (4) The median and paired fins are present. The pelvic fins (in male) are provided with claspers. The fins are supported by the fin-rays. (5) The tail is heterocercal. (6) Paired sensory capsules are joined with the skull. (7) The notochord is persistent. The vertebrae are complete and separate. (8) The mouth is ventrally placed. Rows of teeth (specialised placoid scales) are present in the mouth. The spiral valve is present in the intestine. (9) The nostril may be one or two in number, but do not open into the mouth cavity. (10) The swim bladder is absent. (11) The heart possesses a contractile conus arteriosus with rows of valves. (12) The respiratory organs comprise of five to seven pairs of gills. Each gill is placed in a separate cleft. No operculum is present over the gills except Holocephalans. (13) The sexes are separate. The gonads are typically paired and the gonoducts open into the cloaca. (14) The eggs are large and yolky. Fertilization is internal. Cleavage is meroblastic, i.e., incomplete. Development is direct.

The class Chondrichthyes includes the surviving gnathostomes. Due to the lack of complete fossil records and intermediate stages, the subdivision of the class Chondrichthyes remains unsatisfactory. However, all the cartilaginous fishes can be divided into two subclasses, *Selachii* and *Bradyodonti*. The subclass Selachii includes four orders, viz., *Cladoselachii*, *Pleuracanthodii*, *Protoselachii* and *Euselachii*. The subclass Bradyodonti has only two orders, *Eubradyodonti* and *Holocephali*.

Subclass (1) Selachii

The members of this subclass possess the gills placed in separate clefts and a spiracle is present behind each eye.

The subclass Selachii has four orders under it. The orders are:

Order 1. *Cladoselachii* or *Pleuropterygii*. This order includes the extinct forms ranging from the Devonian to Permian periods. The Cladoselachians represent the ancestral group of sharks from which all modern sharks have been originated. The body is fusiform in shape. The tail is heterocercal. Two dorsal fins are present. The pectoral fins are very prominent. The mouth is subterminally placed. The teeth are elongated and sharp. The jaw suspension is of amphistylic type. Claspers are absent. The examples are: *Cladoselache*, *Cladosus*, *Symmorium*, *Goodrichia* and many others. The genus *Diademodus* is regarded as an early offshoot of the chondrichthyan stock. Diademodus has many cusped teeth and the dorsal fin lacks spines. The Cladoselache is a specialised side-line of the main chondrichthyan stock. Goodrichia is recorded to be 2·5 m in length.

Order 2. *Pleurocanthodii* or *Ichthyotomi*. The pleurocanthodians form a specialised group of fossil sharks which have been derived from the Devonian cladoselachains. They are fresh water forms. The fossils were abundant from late Devonian to Triassic period. The body is slender with the dorsal fin extending along the body and tail. The diphycercal tail has equally developed blade of fin above and below the notochord. The epichordal and hypochordal rays are equally developed. The paired fins are paddle-like and have "archipterygium" pattern, i.e., having a long axis with pre- and post-axial rays. The archipterygial fin is supposed to be the ancestral type of all fins. A long spine is present on the head. The claspers are present. The typical example is *Pleurocanthus*.

Order 3. *Protoselachii*. The protoselachians flourished well in the Palaeozoic seas and they became nearly extinct in the Permian to Triassic period. Some species belonging to the genus *Heterodontus* are still surviving to-day. The pectoral fin is notched at the posterior margin. The claspers are present in the males. Two types of teeth are present. The sharply pointed ones are located anteriorly and the flattened types are placed behind for crushing the molluscan shells.

Order *Euselachii*. In the Jurassic period, the sharks diverged into two main lines—the Pleurotremata or true sharks and the Hypotremata or skates and rays. They are abundant from the Jurassic to the recent times. They possess numerous teeth developed in succession. The pectoral fins have three basal pieces. Depending on the position of gill-slits, the euselachians are grouped under two suborders, Pleurotremata and Hypotremata.

Suborder Pleurotremata

This suborder includes the true sharks. They are very swift swimmers. The teeth are very sharp. The body is spindle-shaped and the tail is heterocercal. There are five to seven pairs of gill-slits and these are laterally placed. The pectoral fins are small and the anterior margin is free from the body. The hyomandibular and the ceratohyal support the first gill. The Pleurotremata is divided into three divisions, Notidanoidea, Galeoidea and Squaloidea.

Division—Notidanoidea

This division embraces the primitive true sharks with an amphistylic jaw suspension. An unconstricted notochord is present. 12 to 14 gill-slits are present. The examples are: *Hexanchus*, *Heptranchias* and *Chlamydoselache*. *Hexanchus* and *Heptranchias* are long-bodied and viviparous forms.

Division—Galeoidea

The sharks under this division have elongated body with two dorsal fins. These fins are not supported by spines. The members of this division exhibit diversity in structure and habitat. The examples are *Cetorhinus*, *Rhineodon*, *Scylionhinus*, *Mustelus*, *Carcharodon*. Carcharodon is a man-eating shark of about 9 m long. Some fossil representatives of this group have been estimated to have reached about 27 m in length.

Division—Squaloidea

This division is characterised by having a spine in front of each dorsal fin. The squaloidea includes many well-known sharks like *Squalus* (spiny dogfish), *Scoliodon* (*Scoliodon sarrakowah* is the common Indian species), *Pristiophorus* (saw-sharks), *Squatina* (angle-fish), *Alopias* (thresher shark), etc.

Suborder—Hypotremata

The skates and rays are included in this suborder. The members are quite abundant from the Jurassic to recent times. They are modified to live on the bottom of the sea in shallow waters. They possess blunt teeth and devour the invertebrates. The locomotion is being effected by producing waves of contraction that pass backwards along the fin. The body is depressed and gill-slits are ventrally located. The pectoral fins are enlarged and become fused with the sides of the body and head. The hyomandibular does not support the gill. The eyes have shifted on the upper surface of the head and are provided with eyelids. Each spiracle is provided with valves which shut at expiration. The examples are *Rhinobatis* (banjo-ray), *Pristis* (saw-fish), *Raja* (common rays and skates), *Torpedo* (electric-ray), *Mobula* (sea-devil), *Myliobatis* (eagle-ray), etc.

Subclass (2) Bradyodonti

This subclass constitutes an aberrant group of cartilaginous fishes which diverged from the main chondrichthyan stock at the Carboniferous period. Unconstricted notochord is present. The vertebrae are reduced to nodules. The teeth are modified into crushing plates which are firmly attached to the jaws.

The Bradyodonts are divided into two orders—*Eubradyodonti* and *Holocephali*.

Order *Eubradyodonti*. They are the primitive bradyodonts which originated in the upper Devonian and became extinct at the end of Palaeozoic. They possess the characteristic dentition. They preserve many primitive features of the group in the nature of vertebrae, mode of jaw suspension and in the cleavage pattern. The teeth are few in number and fuse to form flattened crushing plates. The examples are: *Helodus*, *Cochliodus* and *Psammodus*.

Order *Holocephali*. The Holocephali arose probably in Triassic period and exist to-day as the strange chimaeras of the deep seas. The mouth is reduced to a small aperture bounded by lips. The head has the appearance like that of parrot. They have holostylic jaw suspension. The operculum is present which is attached to the hyoid arch. Extra claspers of unknown function are present on the head of males and these are called the *cephalic claspers*. The teeth are absent. The spiracles are absent. The tail is slender and whip-like. The cleavage is holoblastic. The examples are *Chimaera monstroso* (rat-fish), *Callorhynchus antarcticus* and *Harriotta raleighana*.

CLASS III—**Osteichthyes**

The members of the class constitute the highly-developed forms amongst the fishes. They possess many diagnostic features which separate them from other classes of fishes. The members of this class of fishes exhibit wide range of adaptive radiation. Despite this fact they possess many common characters. These are: (1) The skin contains many mucous glands and the dermal scales are of ganoid, cycloid or ctenoid types. The scales may be absent in a few forms. (2) The unpaired and paired fins are mostly present. The fins are supported by bony fin-rays. The tail is homocercal. (3) The mouth is terminal and is provided with teeth. The olfactory sacs are two and are dorsally placed. They have no connection with the mouth cavity. (4) The skeleton is chiefly composed of bone. In sturgeons and some others the skeleton is cartilaginous. The jaw suspension is either hyostylic or amphistylic. (5) The heart is two chambered (one auricle and one ventricle) with sinus venosus and conus arteriosus. Four pairs of aortic arches are present. (6) Respiration takes place by gills which are covered by opercula. Usually a swim bladder is present. (7) The gonads are usually paired. They are usually oviparous although ovoviviparous and viviparous forms are recorded. Claspers are absent. Metamorphosis may be present.

The class Osteichthyes is divided into two subclasses—Actinopterygii and Crossopterygii.

Subclass (1) Actinopterygii

This subclass Actinopterygii gets its name from the characteristic pattern of the paired fins. The 'ray-finned bony fishes' inhabiting the seas or fresh water are included under the group. The paired fins are provided with basal supports which project outside the body wall. The basal supports are well-developed in ancient forms while in the recent genera these supports are greatly reduced. The fin-web lies outside the body and is supported only by the fin-rays. The body is covered by ganoid scales, but in crossopterygians the scales are of cosmoid type. In actinopterygians, the scales may be modified or absent. The tail is mostly homocercal which may be either semi-heterocercal or heterocercal in a few forms. The investing bones of the skull and jaws become greatly reduced in number in comparison to that of the crossopterygians. The spiracles, abdominal pores and a spiral valve in the intestine are present in primitive actinopterygians, while all these structures are absent in the advanced forms. The conus arteriosus is greatly reduced and a large bulbus arteriosus has been evolved. The conus is represented by one or two rows of valves. The brain is characterised by having the large medulla, cerebellum and corpus striata. The internal nostrils are absent. A pineal aperture is rarely present. Like all other groups of fishes, the classification of the subclass Actinopterygii, into different subgroups is unsatisfactory. The subclass is divided into three superorders, Chondrostei, Holostei and Teleostei. The main differences are tabulated in Table Chordata—6.

Superorder 1. CHONDROSTEI

The superorder Chondrostei is characterised by having (1) persistant notochord, (2) the skeleton is largely cartilaginous, (3) the scales may be absent or may be modified into scutes and (4) the absence of teeth. This superorder includes the following orders under it.

Order 1. *Palaeoniscoidea*. The members of this order are recorded in plenty in the Devonian strata and became extinct by the Triassic. The order is represented by *Cheirolepis*, *Palaeoniscus* and a few others. Although palaeoniscids arose from the same ancestral stock from which crossopterygians evolved, the palaeoniscids differ greatly from the latter. The eyes in palaeniscids are large in size and are provided with four sclerotic plates. Only one dorsal fin is present. The paired fins lack central axis and a series of divergent radials support the fins. The fins assume short and rounded muscular lobes. So the fins are not of archipterygian type. The body is

TABLE CHORDATA—6

	CHONDROSTEI	HOLOSTEI	TELEOSTEI
1. Endoskeleton	Partly cartilaginous.	Partly cartilaginous.	Completely ossified.
2. Spiracular slit	Present.	Absent.	Absent.
3. Tail	Strongly heterocercal.	Abbreviated heterocercal.	Homocercal.
4. Position of Pelvic fins	Usually posterior.	Usually posterior.	Usually anterior.

covered by thick rhomboidal scales which are articulated by peg and socket joints. The scales are of ganoid variety. The palaeoniscids became diverged into different lines during the Carboniferous and Permian periods. The diversification is so great, it becomes difficult to draw the actual relationship between them. Cheirolepis is regarded as the most primitive type having atypical scales, small eyes and a flat skull roof. Examples: *Cheirolepis*, *Birgeria*, *Palaeoniscus*, *Cheirodus*, *Catopterus*, *Perleidus*, *Helichthys*.

Order 2. *Acipenseroidei.* The order Acipenseroidei includes the sturgeons which have descended from the palaeoniscids and is characterised by the reduction of bones. The modern sturgeons inhabit the sea but migrate to the river for spawning. They feed on invertebrates which are collected from the muddy bottom by stirring up with the snout. The snout is elongated. The mouth is ventrally placed, small and provided with barbels. The jaws are weakly developed and are without teeth. The skull and endoskeleton are largely cartilaginous. The scales are also reduced. The tail is covered with small rhomboidal scales and in the rest of the body, there are bony plates bearing spines arranged in five lines. The skin between the lines is beset with denticles. An open spiracle is present. By having the spiral valve in the intestine and the conus arteriosus, the sturgeons resemble the elasmobranchs. But the thin roof of the cerebral hemispheres and retention of many features establish their inclusion under the class Osteichthyes. Examples: *Acipenser* (Europe, North America and Asia), *Scaphirhynchus* or shovel-nosed sturgeon (North America and Central Asia), *Polyodon* or spoonbill sturgeon or paddlefish (Mississipi), *Psephurus* or spoonbill sturgeon (China).

Order 3. *Polypterini* (or *Cladistia*). This order is represented by *Polypterus* and *Erpetoichthys*. The body is slender and is covered with thick rhomboidal scales. The scales are of ganoid variety. The basal part of the pectoral fins is narrow and covered by scales. The dorsal fin bears eight or more fin-lets, each is provided with an anterior spine. The swim bladder is modified into a paired lung-like structures with its outlet into the pharyngeal cavity. The lung-like swim bladder acts as an accessory respiratory organ and helps Polypterus to survive the periodic drought. Because of the presence of such structure, Polypterus is included with the crossopterygians by many authors. The spiracle is present and helps in the expulsion of excess water taken in the mouth cavity. A pharyngeohypophysial duct is present which is closed in adult Polypterus but remains open in Erpetoichthys. The internal nostril is absent. The intestine bears a spiral valve. The larva possesses delicate external gills.

The nature of the scales, presence of spiracle, the orientation of the skull bones suggest to the origin of the group from some palaeoniscid forms.

Examples: *Polypterus* (of Congo, Nile, Niger and Senegal rivers) and *Erpetoichthys* or *Calamoichthys* (of West Africa).

Superorder 2. HOLOSTEI

The members of this superorder are varied in form and evolved from the palaeoniscids during the late Permian. These different types of fishes become flourished during the Triassic and Jurassic times and are collectively called the holosteans. This group of fishes form a structural bridge between the Chondrostei and Teleostei. The group is characterised by having a heterocercal tail fin which may superficially resemble the homocercal type. The body is covered by ganoid scales which lack the middle cosmine layer. The jaw suspension is peculiar and the maxilla remains free from the preopercular. Loss of clavicle from the pectoral fin is a distinctive feature of holosteans. The spiracle is also absent. A single swim bladder is present which is primarily hydrostatic in function. Another important holostean feature is the reduction of fin-rays. This polymorphic group is subdivided into five orders. Most of the representatives are extinct except possibly the fresh water forms. *Lepisosteus* (*Lepidosteus*) and *Amia*.

Order 1. *Semionotoidea.* This order is represented by a single surviving genus *Lepisosteus* (or *Lepidosteus*). These fishes are popularly called the gar-pikes inhabiting the fresh water of central and north America. Lepisosteus exhibits many primitive features. It has an elongated body with a long snout for catching other fishes. The body is covered by thick rhomboidal ganoid scales. The swim bladder opens into the pharynx and has a cellular wall. The tail is nearly symmetrical. The heart presents primitive characters like the presence of a long valvular conus arteriosus and absence of bulbus arteriosus. The clavicle is present in a reduced condition. The spiracle is closed. The pyloric caeca are present. The maxilla is greatly reduced.

The vertebrae are of opisthocoelous type. The jugal plates are absent.

Order 2. *Amioidea*. The members of the order originated in the Mesozoic era, but they persist to-day by a single North American genus *Amia* or Bow-fin. Amia bears an admixture of primitive and specialised characters, The scales become reduced to bony cycloid types. The tail fin is externally symmetrical (homocercal). The swim bladder is modified into a bilobed dorsal 'lung'. The maxilla and the check bones are greatly reduced. The spiral valve is vestigial. The conus arteriosus is reduced but the bulbus arteriosus is considerably developed. The pyloric caeca are absent. There is a single large jugal plate between the rami of the lower jaws. The vertebrae are of amphicoelous type. The eggs are small and the cleavage is holoblastic.

Order 3. *Pycnodontoidea*. This order includes the extinct forms examplified by *Gyrodus*, *Mesturus*, *Pycnodus*, etc. The body is laterally compressed and covered by rhomboic scales. The tail region may lack scales. The opercular apparatus is reduced.

Order 4. *Aspidorhynchoidea*. This order also includes the fossil forms. The vertebral column is composed of ring-shaped amphicoelous vertebrae. The tail fin is homocercal. Examples: *Aspidorhynchus*, *Belonostomus*.

Order 5. *Pholidophoroidea*. This order also includes the extinct holocephalans typified by *Pholidopleurus*.

Superorder 3. TELEOSTEI

Deriving from a holostean stock, the teleosteans constitute the most successful group of fishes. They exhibit great diversities in form, habit and habitat. The super order Teleostei is characterised by the following features: (1) The spiracle is lost. (2) The spiral valve in the intestine is absent. (3) The conus arteriosus is greatly reduced and may be represented by one or two rows of valves. There is an enlarged bulbus arteriosus. (4) The swim bladder is essentially a hydrostatic organ. (5) The scales lack ganoine layer. (6) The maxilla is greatly reduced. (7) The lower jaw is composed of dentary, angular and articular. (8) The clavicle is absent. (9) The endoskeleton is fully ossified. (10) The vertebrae are amphicoelous. (11) The skull bears a single provomer and a single supraoccipital bone. (12) There are intermuscular bones which function as the ribs. (13) The paired fins lack a central axis. (14) The gills are filamentar in nature. (15) The urinogenital system is highly developed. (16) The brain lacks optic chiasma. The roof of the cerebrum is extremely thin. The classification of the Teleostei into smaller groups is a very difficult task because the different evolutionary lines show very little difference.

The superorder Teleostei includes thirty two orders. The characteristics of the orders are described in brief and most of the examples of the orders cited below are Indian species.

Order 1. *Isospondyli* or *Clupeiformes*. The herring-like fishes are included under this order. These fishes may inhabit the fresh water, seas or estuaries. The scales covering the body are well-formed and are of cycloid type. The tail fin is homocercal. A single dorsal fin is present. The ventral fin may be absent. The fins are devoid of finrays. The pyloric caeca are numerous. The Weberian apparatus is lacking. The fishes originated during the Jurassic period and extend upto the present day.

Examples: *Clupea* (Herring), *Salmo* (Trout), *Salmo gairdnerii* (Indian trout introduced from America), *Notopterus chitala* (Chital fish), *Notopterus notopterus* (Faloi fish), *Elops saurus*, *Hilsa ilisha*, *Ilisha elongata*, *Chirocentrus dorab*, *Megalops cyprinoides*, *Albula vulpes*.

Order 2. *Haplomi*. The representatives of the order possess the fins that are provided with soft rays. The pyloric caeca are absent. They extend from the Miocene to the recent. Example: *Esox* (Pikes).

Order 3. *Iniomi* or *Scopeliformes*. The fishes included under the order are deep sea forms. All the fishes possess the phosphorescent organs which develop by the modification of the integumentary glands. The swim bladder is usually absent. The mouth is wide and armed with numerous minute teeth. The dorsal and ventral fins lack spines. The body is almost cylindrical. The fishes extend from the cretaceous period to the recent.

Examples: *Myctophum* and *Synodus* are the foreign genera and are called the lantern fishes. *Harpodon nehereus* of Bombay coast is the single Indian species under the order and is popularly called the 'Bombay duck'.

Order 4. *Miripinnati*. The members of the order are characterised by having scaleless body. The lateral line organs are located on projections. Example: *Miripinna*.

Order 5. *Giganturoidea* or *Giganturiformes*. These fishes are devoid of pelvic fins and swim bladder. The lower lobe of the tail fin becomes elongated. Example: *Gigantura.*

Order 6. *Lyomeri* or *Saccopharyngiformes.* The body of the fish is eel-like and is without scales. The pelvic and caudal fins are lacking. The mouth is large. Example: *Saccopharynx.*

Order 7. *Ostariophysi* or *Cypriniformes.* This order includes a large number of varied forms. The members are characterised by having a peculiar Weberian apparatus between the ear and the swim bladder. The swim bladder is connected with the gut by a duct. The fins are usually provided with spine. The ventral fin is abdominal in position. The representatives of the order are placed under two divisions.

Division 1. Cyprini. The body may be scaleless. The scales, when present, are without bony plates. The third and fourth vertebrae do not fuse with each others.

Examples: *Labeo rahita* (Rohu), *Cyprinus carpio* (common carp), *Labeo calbasu* (Calbash fish), *Catla catla, Cirrhina mrigala* (Mrigal fish), *Puntius ticto, Tor tor, Rasbora daniconius, Carassius auratus* (Gold fish).

Division 2. Siluri. The body is naked. The reduced maxillary bone supports the barbels. The second, third, fourth and fifth vertebrae are usually fused. Examples: *Clarias batrachus* (Magur), *Heteropneustes fossilis* (Singhi), *Wallago attu* (Boyal fish), *Mystus seenghala* (Tengra), *Rita rita, Chaca chaca, Bagarius bagarius.*

Order 8. *Apodes* or *Anguilliformes.* This order includes the eels. The body is elongated and slender. The scales may be lacking, if present, these are very small in size and remain embedded in the integument. The pelvic fins are usually absent, when present, are abdominal in position. The dorsal and anal fins are long and narrow. The fins lack the spines. The swim bladder is connected with the gut by a duct.

Examples: *Anguilla bengalensis* and *Anguilla bicolor* are the fresh water forms. *Muraena punctata* is the marine form.

Order 9. *Heteromi* or *Halosauriformes* or *Notocanthiformes.* The body is slender. The tail is long but the caudal fin is absent. The oviducts are lacking. Example: *Notocanthus.*

Order 10. *Synentognathi* or *Beloniformes.* The body is covered with cycloid scales. The pectoral fins are shifted to the dorsal side of the body and become greatly enlarged. These fishes are mostly marine. The ventral fins have shifted to abdominal side. Examples: Garfishes (*Strongylura strongylura, Xenentodon cancila*), Flying fishes (*Exocoetus volitans, Cypselurus poecilopterus*) and Halfbeak (*Hemirhamphus georgii*).

Order 11. *Salmopercae* or *Percopsiformes.* This order includes the North American genera, *Percopsis, Columbia.* The dorsal and ventral fins are preceded by one to four spines.

Order 12. *Microcyprini* or *Cyprinodontiformes.* The order includes many small sized fishes where the pelvic fins may be absent. The fins are spineless. The mouth is protractile. There is a single dorsal fin. Examples: Cave fish (*Typhlichthys*), Top Minnows (*Cyprinodon, Gambusia*).

Order 13. *Solenicthhyes* or *Syngnathiformes.* The mouth is placed at the tip of a tubular snout and is suctorial. The body is covered with scales or bony rings. The males possess brood pouch for the development of the youngs. Examples: Sea horse (*Hippocampus*), Pipefishes (*Syngnathus, Trachyrhamphus*). The typical Indian species of pipefish is *Trachyrhampus serratus.*

Order 14. *Anacanthini* or *Gadiformes* or *Macruriformes.* The members •under the order have soft-rayed fins, i.e., the fins lack spines. The body is covered by cycloid scales. The swim bladder lacks duct. Examples: Cods (*Gadus, Bregmaceros*), Hakes (*Merluccius*), Burbots (*Lota*).

Order 15. *Allotriognathi* or *Lampridiformes.* The fishes are marine. The eyes are very large. The teeth are either feebly developed or absent. Examples: *Lampris, Trachypterus, Regalecus.*

Order 16. *Berycomorphi* or *Beryciformes.* The fishes belonging to the order are mostly the deep sea forms. The pelvic fins bear more than five soft rays. Example: Squirrel fish (*Holocentrus*).

Order 17. *Zeomorphi* or *Zeiformes.* The anal fin is preceded by one to four spines which form separate fins. Example: *Zeus faber.*

Order 18. *Percomorphi* or *Perciformes.* This order includes a large number of fishes popularly called the perches. The fishes show great diversity in form and habit. The dorsal and anal fins are provided with both spiny and soft fin-rays. Two dorsal fins are present. The Weberian apparatus is absent. The swim bladder lacks a duct.

Examples: *Scomber, Etheostoma, Perca, Micropterus, Lates calcarifer* (Bhetki), *Chaetodon vegabundus* (Angle fish), *Toxotes microlepis* (Archer fish), *Tilapia mossambica*

(American koi), *Trichiurus haumela* (Ribbon fish), *Rastrelliger kanagurta* (Mackerel), *Pterois russelii* (Scorpion fish), *Stromateus argenteus* (Silver promfret) *Anabas testudineus* (Koi fish).

Order 19. *Gobimorphi.* The fishes under the order are carnivorous and some are marine. They have suborbital ring devoid of a bony support for the operculum. The gills are four and the gill-membrane is attached to isthmus. The pelvic fins are located below the pectorals and each pectoral contains one spine and four or five soft rays. The first dorsal fin may contain a few weak spines. The pyloric caeca and swim bladder are absent. Examples: *Gobius, Periophthalmus, Boleophthalmus.*

Order 20. *Scleroparei.* The mail-cheeked fishes constitute the order. Extra spines are present over the head and body. A bone may be present across the cheek. Examples: *Sebastes, Cottus, Gasterosteus.*

Order 21. *Thoracostei* or *Gasterosteiformes.* The scales covering the body become modified into spines. The number of the spines may vary from three to ten. Example: *Gasterosteus.*

Order 22. *Hypostomides* or *Pegasiformes.* The fishes are smaller in size. The body is enclosed in a bony box. Example: Dragon fishes (*Pegasus*).

Order 23. *Heterosomata* or *Pleuronectiformes.* The fishes under this order are adapted for bottom living. The body is highly compressed and the eyes are shifted to one side of the dorsal side of the head. The fins lack spines. The swim bladder is absent. The head is asymmetrical. Examples: *Solea ovata, Psettodes erumei, Cynoglossus lingua.*

Order 24. *Discocephali* or *Echeniformes.* The order includes the sucker fishes where the first dorsal fin is modified into a flat oval adhesive disc on the upper surface of the head. The other dorsal fin and the anal fin are spineless. The body is covered by cycloid scales. The swim bladder is absent. Examples: *Remora remora, Echeneis naucrates.*

Order 25. *Plectognathi* or *Tetrodontiformes.* The fishes have short and powerful jaws. The scales become modified into spines. Examples: Globe fishes (*Tetrodon cutcutia, Tetrodon patoca*), Trunk fish (*Ostracion gibbosus*), Porcupine fish (*Diodon hystrix*), Sun fish (*Mola mola*).

Order 26. *Malacichthyes* or *Icosteiformes.* There are no spiny rays in the fins and the endoskeleton is less ossified. Example: *Icosteus.*

Order 27. *Xenopterygii* or *Gobiesociformes.* The fishes have naked body with an adhesive disc on the abdomen. Example: *Gobiesox.*

Order 28. *Haplodoci* or *Batrachoidiformes.* The fishes have a very wide mouth and a depressed head. Examples: Toad fishes (*Porichthys, Opsanus*).

Order 29. *Pediculati* or *Lophiiformes.* This order includes the Angler fishes and some deep sea fishes. The spinous dorsal fin bears a few flexible rays which become dilated at the terminal ends. The fishes possess luminescent organs. Example: Angler fish (*Antennarius*).

Order 30. *Opisthomi* or *Mastacembeliformes.* The fishes under the order are called the spiny eels. They have eel-like body with tubular nostril situated on fleshy tentacle at the end of the snout. The dorsal, caudal and anal fins become united to form a continuous fin. In *Macrognathus,* the caudal fin has a separate entity. Many free spines are present on the dorsal side of the body. The pectoral fins are present. Examples: *Mastacembelus, Macrognathus.*

Order 31. *Synbranchii* or *Synbranchiformes.* This order also includes the eel-shaped fishes. The body is elongated with the dorsal and ventral fins devoid of fin-rays. The pectoral fins are absent. Examples: *Amphipnous cuchia, Symbranchus bengalensis.*

Order 32. *Channiformes.* The order Channiformes includes commonly the snake headed fishes. The head is depressed and covered by large plate-like scales. The fins are devoid of spines. The swim bladder lacks a duct. The accessory respiratory organ (suprabranchial organ) is present. Examples: *Channa* (*Ophiocephalus*) *punctatus* (Lata fish), *Channa striatus* (Shole fish), *Channa gachua* (Chang fish), *Channa marulius* (Shal fish).

Subclass (II). Crossopterygii (Choanichthyes)

The lung fishes and their allies are included under this subclass. The crossopterygians represent a very interesting group of fishes and present many characteristics of the tetrapods. This group is represented to-day by four living genera, but the relics of the group can be traced back to the Devonian period. The subclass crossopterygii possesses the following features: (1) The paired fins are provided with a large median lobe and are covered by scales. (2) The pectoral fins are supported by a jointed median axis, with radials arranged on its two sides. (3) The body is covered with scales. Scales are covered by thick cosmine layer. (4) The swim bladder is modified into 'lung'. (5) The nostrils open into the mouth cavity. (6) The jaw suspension is autostylic. The subclass Crossopterygii includes two orders: Rhipidistia and Dipnoi.

Order 1. *Rhipidistia.* This order includes the members of the fishes which possibly hold the key of tetrapod evolution. These fishes have ossified skull and the teeth are borne on both the premaxilla and maxilla. The tail is partly heterocercal.

Suborder (i). Osteolepidoti.

These fishes arose during the mid-Devonian period and constitute the earliest and most primitive members of the crossopterygians. They become extinct during the permian period. The characteristic features are: (1) The body is elongated with two dorsal fins. (2) The tail fin is heterocercal. (3) The paired fins assume a scaly lobed form. (4) The pectoral fins are supported by a basal element. This element is attached with the pectoral girdle by one end and the tip is provided with slender branching rods. (5) The body is covered by thick, pitted rhomboidal cosmoid scales. (6) The skull is well ossified and composed of series of bony plates. The head bones are also covered by a layer of cosmine. The top of the skull is divided into two parts by the presence of a transverse joint between the parietal and postparietal. An unossified gap is present at the base of the skull. (7) The jaw suspension is of autostylic type. (8) The teeth are simple cones. Two types of teeth are present in Osteolepidoti. The premaxilla, maxilla and dentary are supplied with many shaply pointed small conical teeth. Besides these small teeth, the prevomer, palatine and epipterygoid bear large teeth which can be replaced. These teeth show a peculiar infolding of the enamel. This feature is not found in other fishes but resembles that of earliest tetrapods. (9) The eyes are small and supported by many sclerotic plates. Examples: *Osteolepis*, *Megalichthys*, *Rhizodus*, *Eusthenopteron*, *Thursius*.

Suborder (ii). Coelacanthini or Actinistia

The osteolepids became extinct by the early Permian, but an isolated line arising from them evolved directly into the coelacanths. The coelacanths leave behind a good fossil record and survive to-day by a single genus *Latimeria chalumnae*. The coelacanths are characterised by having the following features: (1) The internal nostrils are absent in the fossil forms. (2) The tail fin is diphycercal with three distinct lobes. (3) There are two dorsal fins. (4) The paired fins assume short pedunculate lobed structure. These paddle-like fins are covered by scales and the fin-rays are attached in a fan-shaped fashion. (5) The vertebral column is mostly unossified. The notochord persists as a massive unconstricted rod. The neural and haemal arches may be present. (6) A calcified swim bladder is present. (7) The teeth are borne only at the tip of the premaxilla and dentary.

Examples: *Caelacanthus*, *Macropoma*, *Undina*, *Latimeria chalumnae*

Order 2. *Dipnoi* or *Dipneusti* or *Dipneumones.* The Dipnoans or 'lung-fishes' constitute this order. The position of the dipnoans amongst the fishes is quite significant. They constitute a sort of transitional group between the teleostei and the amphibians. The lung-fishes originated during the middle Devonian and flourished well in the Permian and Triassic periods. They are surviving to-day by three living genera, *Neoceratodus*, *Protopterus* and *Lepidosiren*. The living dipnoans are classified under two suborders Monopneumona and Dipneumona.

Suborder 1. Monopneumona

The dipnoans having a single 'lung' fall under this suborder. The jointed lateral rays of the paired fins are well developed. The typical representative is *Neoceratodus*. The mesozoic form, *Ceratodus* is also included under it.

Suborder 2. Dipneumona

The dipnoans with double 'lungs' are included under this suborder. The lateral rays of the paired fins are extremely reduced. The lateral rays may be absent. Examples: *Protopterus* and *Lepidosiren*.

Besides the surviving genera, many remarkable extinct genera are also recorded. The mid-Devonian genus, *Dipterus* is the most primitive dipnoan recorded in the geological history. The upper Devonian genera are: *Pentlandia*, *Scaumenacia*, *Phaneropleuron*, *Rhynchodipterus*, *Fleurantia*. *Uronemus* is present in lower Carboniferous, *Conchopoma* in the lower Permian and *Ctenodus*, *Sagenodus* are recorded both in the Carboniferous and Permian periods.

GENERAL ORGANISATION ON FISHES

Fishes have undergone extensive adaptive modifications and exhibit an endless variety of forms in different environments. The organisation of the fishes is so diverse that it is difficult to give a complete and comprehensive account of the group.

SIZE

The fishes vary extensively in size ranging from 10 mm long tiny *Pandaka* (Philippine goby) to the giant tertiary elasmobranch, *Carcharodon* of about 24 m long. The largest living fish is *Rhinodon* (oviparous whale shark of tropical seas) which attains a length of 21 m. The dogfishes of the genus *Squalus* grows to an average

TABLE CHORDATA—7

Comparison between Chondrichthyes and Osteichthyes

Features	CHONDRICHTHYES	OSTEICHTHYES
1. Habitat	Mostly marine.	Both fresh water and marine.
2. Exoskeleton	The body is covered by placoid scales. The teeth are modified placoid scales.	The body is provided with thin overlapping scales. The scales are of cosmoid, ganoid, cycloid or ctenoid types.
3. Caudal fin	The caudal fin is upturned and asymmetrical (Heterocercal).	Symmetrical (Homocercal). The caudal fin may be secondarily isocercal, gephyrocercal, abbreviated homocercal or diphycercal.
4. Topography of mouth	The mouth is situated on the ventral surface of the head. The position is actually subterminal.	The mouth lies terminally.
5. Gill-openings	In most of the fishes, except certain primitive sharks, there are usually five pairs of gill-openings. In holocephalans, operculum is developed.	The gill-openings are covered by operculum so that a single exit is visible on each side.
6. Spiracles	In all the rays and some sharks, a pair of spiracles opens just behind the eyes.	Spiracular openings are absent.
7. Claspers	The males are provided with claspers to introduce sperms into the genital tracts of females.	The clapsers are absent.
8. Endoskeleton	Cartilaginous.	Mostly bony.
9. Jaw suspension	Hyostylic.	Mostly amphistylic.
10. Intestine	Short and its lumen contains complicated spiral valve.	Long and is devoid of spiral valve.
11. Swim bladder	Absent.	Present.
12. Eggs	Females lay a few large eggs or give birth to live youngs.	Females lay numerous small eggs.
13. Fertilization	Internal.	The eggs and sperms are shed into the surrounding water and fertilization is external.

length of about 1 m. Majority of the sharks do not exceed 2.5 m.

The rays are mostly 30–90 cm in length and the giant ray, *Manta birostris* (Devil fish) measures 5.1 m in length and 6.5 m across the pectoral fins. *Bathytoshia* (a Pacific sting ray) reaches 4.2 m in length and a width of about 2 m. The chimaeras are usually less than 90 cm in length.

The bony fishes are variable in size and no bony fish attains a length rivalling that of the largest known sharks. Most of them are under 1 m in length. *Huso huso* (a sturgeon) grows to a length of 7.2 m. *Sphyraena* (tropical and subtropical barracudas) reaches about 2.4 m and *Serrasalmus* (river-dwelling Piranha) rarely exceeds 60 cm in length. *Mistichthys luzonensis* (a Philippine goby) measures 13 mm in length. *Tetrapturus* (spear fish) grows more than 4.2 m in length, *Istiophorus* (sail-fish) is about 3.6 m and *Arapaima gigus* (south American Spear-fish) attains a length of about 4.5 m.

SKIN

The skin of fish is composed of *epidermis* and *dermis*. A thick basement membrane is present between the dermis and epidermis. The epidermis is multilayered, but the *stratum corneum* is absent. The dermis is made up of connective tissues, blood vessels, nerves and smooth muscle fibres. The scales remain embedded in the dermis. The epidermis of fishes contains large *mucous cells* or *Becker's cells* and *chromatocytes*. The chomatocytes are also present in the dermis. Besides the mucous cells, two types of sensory cells (*granular sensory cells* and *club cells*) are encountered particularly in Actinopterygian fishes. The dermis is composed of the *stratum laxum*, the *stratum compactum* and a *subcutaneous layer*. The stratum laxum is a laminated fibrous layer into which the bases of the scales are held by Sharpey's fibres while the stratum compactum is made up of a reticulum of delicate fibres. All these three layers are sharply demarcated from each other. The skin glands become modified in many fishes. The *poison glands* and the *photophores* are the modified skin glands. The *pterygopodial glands* situated at the root of the claspers of some rays and skates are modified skin glands. These glands help in the sexual activities.

FIN SYSTEM

The fins constitute the major propulsive organs in fishes. These are either the folds of skin or the projections from the body surface. The fins are supported by the fin-rays. These supporting rays may be bony, cartilaginous, fibrous or horny. There are mainly two types of fins in fishes: (1) *Unpaired* or *median fins* and (2) *Paired fins*. The median fins include the *dorsal*, the *caudal* and the *anal*. The paired fins are the *pectorals* and the *pelvics*. These paired fins correspond to the paired appendages of the land vertebrates. A great variety of fins is observed in fishes. The diversity in the fin system in fishes is due to their adaptive responsiveness.

Origin of fins. The median or unpaired fins in fishes have been originated from a continuous fold of tissue. This fold extends from the posterior region of the head and continues posteriorly around the tail and forward upto the anus. This fold is supported by series of parallel cartilaginous rods. In course of development each supporting rod is divided into a lower piece, i.e., *basal*, embedded in the body wall and an upper piece lying in the fin fold, i.e., *radial*. From such a continuous fin-fold, the dorsal, caudal and anal fins have been evolved by the restriction of the radials at certain areas and the progressive degeneration of the fold between them. This concept is supported by the embryological evidences and the unpaired fins in most of the existing fishes developed ontogenically from such a continuous fin-fold. Most of the Ichthyologists are convinced regarding the derivation of the unpaired fins from the continuous fin-fold, but controversy exists as regards the origin of the paired fins in the phylogenetic development of the fishes. Two main theories are: (A) Gill-arch theory and (B) Fin-fold theory.

Gill-arch theory. The idea of the origin of the paired fins from the gill-arches was advanced by Gagenbaur. According to him, the paired fins are the modified gill structures and the girdles represent the gill-arches. The position of the pelvic fins is explained on the assumption that some of the posterior gill-arches have been shifted posteriorly. This idea finds no support from the embryological, morphological and palaeontological studies.

Lateral fin-fold theory. This theory was first proposed by Balfour and Thacher and later on supported by most eminent Zoologists, like Wiedershiem, Parker, Goodrich and many others. According to this theory, the paired fins have originated from a paired *lateral fin-folds* running down each side of the body behind the gill openings upto the end of the tail (Fig. 5.56). These lateral fin-folds are separated at the anterior part, but become fused posteriorly as a median ventral fin-fold. There is also a continuous median dorsal fin-fold. The condition of the lateral fin-folds in the ancestral forms was presumably like the metapleural folds of *Branchiostoma*. Existence of such lateral fin-folds is furnished by an archaic fossil vertebrate, *Jamoytius kerwoodi* discovered from the upper Silurian and also from the study of some fossil cyclostomes and some primitive fishes. There are many palaeontological and embryological evidences in favour of the origin of the paired fins from the lateral fin-folds. Some of the evidences are: (1) Although the structure of the paired fins varies greatly in different fishes, the mode of development is strikingly similar. The embryological stages of fin formation give support to the presence of continuous fin-fold. (2) The condition of the paired fins in an extinct shark, *Cladoselache* adds more weight to this idea. The pectoral and pelvic fins in this form are very wide and lack posterior and anterior notches from the body wall. Presence of such constrictions is a characteristic feature of other fishes. The fins are supported by parallel arrangement of simple cartilaginous rods. Such an arrangement of supporting rods and lack of notches are suggestive of the origin of the fins from the continuous fin-folds. (3) In lower Devonian placoderms (Acanthodians), a series of spines extends ventrally from behind the head to the anal fin. This also suggests the presence of continuous fin-fold. The idea of the fin-fold origin of the paired and unpaired fins in fishes is supported by the anatomical, embryological and palaeontological evidences. This theory is accepted by all the workers in this field of research and the gill-arch theory of Gagenbaur has become a theory of historical importance.

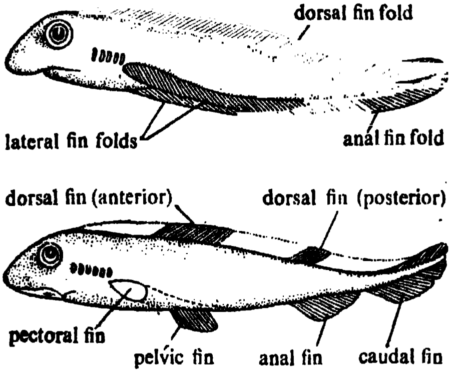


Fig. 5.56. Schematic representation of the derivation of the fins in fishes according to the fin-fold theory.

UNPAIRED FINS

As stated above the unpaired fins include the dorsals, caudal and anal.

Dorsal and anal fins. These unpaired fins show great variation in structure and disposition. Amongst the Chondricthyes, the primitive living forms like *Chlamydoselachus*, *Heptranchias* and *Hexanchus* possess single dorsal fin, while in the rest of the forms the dorsal fins are two in number. The fins are supported by many horny fin-rays (*ceratotrichia*) located beyond the cartilaginous radials. Both the *ceratotrichia* and the *radials* remain completely covered by the integument. But in the bony fishes, the radials lie in the muscles and the basals within the body. In higher teleosts, the radials become reduced to bony or cartilaginous nodules. The nodules are situated within the muscles of the body and are attached with the fin-rays (*lepidotrichia*). The fin-rays are actually the modified scales. Usually the number of the fin-rays corresponds directly to the number of the radials, but in the Dipnoans and Sturgeons, the fin-rays exceed the number of the radials.

In many actinopterygians, the dorsal fin is preceded by many spines. Presence of a single dorsal fin is a primitive feature amongst the actinopterygians. This condition is observed in fossil forms as well as in some extant creatures like *Lepisosteus* and *Acipenser*. In higher forms there are two dorsal fins. The crossopterygians possess two dorsals, of which the posterior one is larger excepting in *Latimeria* where the condition is just reverse, i.e., the anterior one is larger. In *Polypterus*, the dorsal fin is divided into a number of fin-lets, each is having one stout spine supporting a membranous flap.

The modifications of the unpaired fins are related with their particular role in propulsion. In the sharks, the dorsal fins are well-developed and act as the stabiliser, but in the rays the dorsal fins are reduced because they are adapted to live at the bottom of the sea. In Sting rays and Eagle rays, the dorsal fins are totally absent. In Bull-headed sharks, both the dorsals are preceded by a strong shapely pointed spine. The spines are defensive organs and are also associated with the poison glands as seen in *Squalus* (spiny dog fish). In bony fishes the dorsal fin shows extensive variations, specially in shape, size and position. It is present in almost all the forms excepting *Electrophorus* (Electric eel) where it is either lost or reduced to a mere filament-like structure. In primitive bony fishes, the fins are supported by flexible rays and in the actinopterygians the rays have converted into stiff spines. In an eel, *Acanthenchelys*, the dorsal fin is supported by both soft rays and stiff spines. The development of the spines in the unpaired fins in many fishes added a new function of defence in addition to their role in propulsion. The spines exhibit great variations amongst the fishes. In many fishes, notably *Trachinus* and *Synanceia*, the spines supporting the dorsal fin are connected with the poison glands.

Extreme modification is observed in the sucker fishes (*Echeneis*, *Remora*) where the spinous dorsal fin becomes transformed into an oval *adhesive disc* over the head. In Angler-fishes, the dorsal fin is highly modified. The first ray of this spinous fin is located on the snout and transforms into a flexible filament with a membranous appendage at its tip. In deep sea Angler-fishes inhabiting the totally dark realm, a *luminous bulb* is present on this appendage. The luminous bulb varies in shape and size and produces light to attract small fishes. In *Lasiognathus*, this appendage is composed of a stout rod-like basal part and a slender filament. Besides the luminous bulb, a series of non-functional hooks is present.

The anal fin, like that of other unpaired fins, also shows variation in shape and size in different fishes. In fishes, where this fin acts as a locomotory organ, the anal fin is greatly elongated. It is usually supported by soft rays. In some forms, a few anterior rays become transformed into spines. The anal fin is mostly single, but in *Gadus* and some other related forms the anal fin is divided into two parts. The anal fin in the males of the South American and South American Cyprinodonts becomes modified into complicated *intromittent organs*. The third to fifth fin-rays are enlarged and contain either a groove or closed tube into which the reproductive ducts open.

Caudal fin. Of the unpaired fins, the caudal fin plays the important role in forward propulsion during swimming. The caudal fin is highly developed in most fishes excepting *Hippocampus* and some of the eels under the order Anguilliformes. In Hippocampus (Sea Horse) the tail is prehensile. In bottom-living Rays, the caudal fin tends to become reduced and in the Sting Rays the caudal fin is lacking. The tail in the latter forms is produced into a long whip-like tapering structure. The caudal fin in the rest of the fishes exhibits a good deal of variation (Fig. 5.57). Three major types of caudal fins are encountered in different fishes.

Protocercal or Diphycercal. This type of caudal fin is regarded to be the most primitive type. The vertebral column extends upto the tip of the tail and divides the caudal fin into two equal halves. The dorsal half is called the *epichordal lobe* and the ventral one is known as the *hypochordal lobe*. The epichordal and the hypochordal parts of the caudal fin are equal and symmetrical (Fig. 5.57 A, B, C). All the fishes pass through this stage during development. In the living dipnoans, the caudal fin is of protocercal type. In Latimeria, this condition is slightly modified. It is protocercal with a sharply marked median lobe. Presence of *protocercal* tail in some highly developed fishes is possibly due to secondary modification.

Heterocercal. In this case the vertebral column bends upwards. As a consequence the caudal fin is divided into two unequal halves. The vertebral column is bent upwards and continues almost upto the tip of the fin. The epichordal part is greatly reduced while the hypochordal lobe is specially enlarged to make the caudal fin asymmetrical both internally as well as externally (Fig. 5.57D). This type of caudal fin is found in elasmobranch, extinct crossopterygian and primitive actinopterygians. In most elasmobranchs, the caudal fin is usually *heterocercal*, but in Chimaera and Chlamydoselachus the caudal fin is of *isocercal* type (Fig. 5.57E).

Homocercal. This type of caudal fin is the characteristic of the higher bony fishes. The fin is symmetrical externally but internally it is asymmetrical (Fig. 5.57G). The posterior end of the vertebral column is turned upwards and becomes greatly reduced. The tip of the vertebral column is not reached to the posterior limit of the fin. There is no apparent dorsal lobe but the ventral lobe is greatly enlarged and divided into two equal superficial lobes. Most of the teleosts retain the typical *homocercal* condition, but in some forms this condition is slightly modified. The modified caudal fins are: (1) In Cod and Tuna, the homocercal condition is modified. The upward terminal portion of the vertebral column is withdrawn. (2) In some deep sea fishes, (Anguilliformes, Notopteridae, Gymnarchidae, Macruridae) the upturned tip of the vertebral column becomes elongated and straightened out. The fin is actually the marginal extension above and below the elongated vertebral tip. The fin is supported by rays. Such a type of caudal fin is called the isocercal. Developmentally, the isocercal tail is formed by the reduction of size of the hypochordal lobe and elongation of the dorsal and anal fins—so that a continuous fin-fold is re-established. (3) In *Fieraspis* and *Orthagoriscus*, the caudal fin is completely disappeared with the truncation of the vertebral column. Such a type of fin on a rounded caudal lobe is regarded the *gephyrocercal* fin (Fig. 5.57K).

The protocercal or diphycercal type of caudal fin is considered the most primitive type, the heterocercal as the

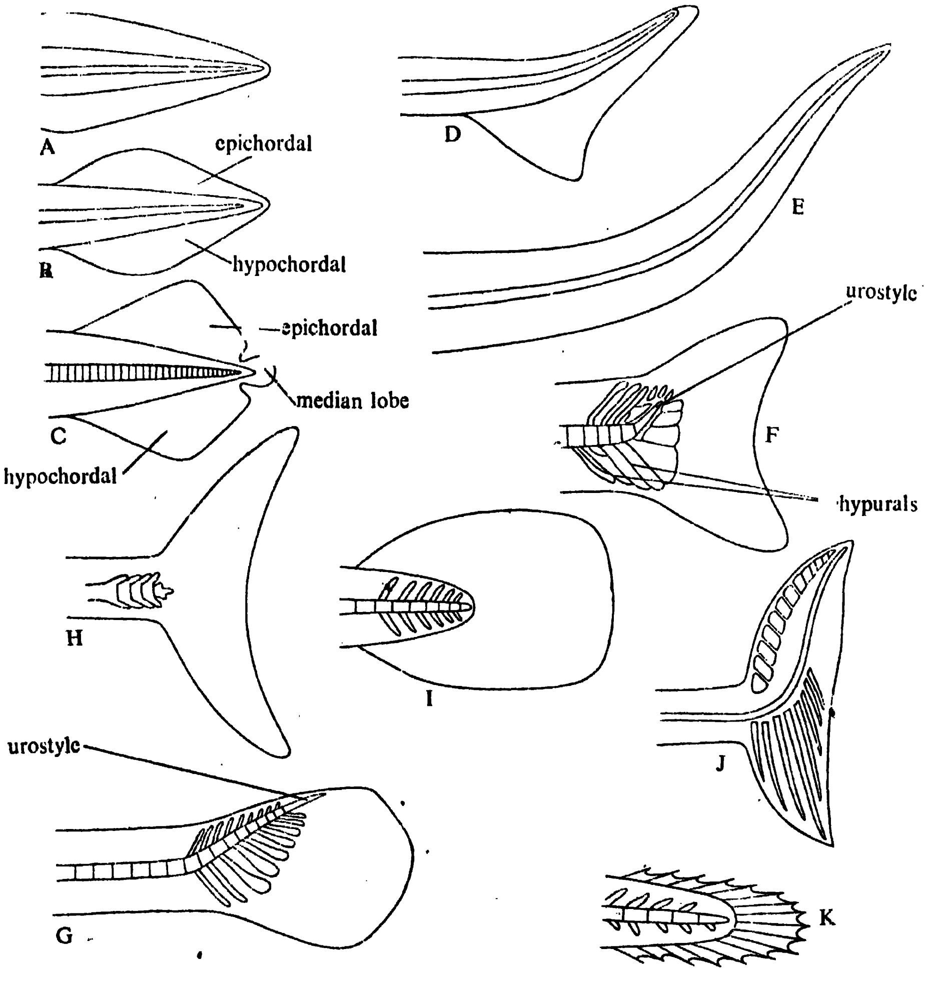


Fig. 5.57. Different types of caudal fins in fishes. A. Protocercal. B. Diphycercal. C. Modified diphycercal. D. Heterocercal. E. Isocercal. F. Homocercal. G. Modified homocercal in *Amia* and *Lepisosteus*. H. Modified homocercal in *Tuna*. I. Modified homocercal in Cod. J. Modified heterocercal in *Cladoselache*. K. Gephyrocercal in *Fieraspis*.

intermediate stage and the homocercal condition represents the advanced stage. In many teleosts, the caudal fin starts as a diphycercal then becomes heterocercal and finally assumes the homocercal condition. The transition of three types of caudal fin in the developmental history of fishes is significant from the phylogenetic point of view. That the homocercal caudal fin is derived from the heterocercal type is evident from the transitional types amongst the extinct and living bony fishes. In primitive forms like *Acipenser* and *Polyodon*, the caudal fin is strongly heterocercal, while in *Amia* and *Lepisosteus*, the caudal fin exhibits an intermediate condition between the heterocercal and homocercal type. The vertebral column is shortened and retracted at the base of the caudal fin. The fin has retained the reduced upturned fleshy epichordal lobe, but the hypochordal lobe is greatly enlarged to form only the anteroventral lobe. This condition is called either *hemiheterocercal* or *abbreviated homocercal* type. Most of the early fishes possess heterocercal type of caudal fin. From the heterocercal condition the homocercal caudal fin is evolved by the gradual reduction of the upward (epichordal) fleshy lobe. The homocercal condition is transformed into isocercal or abbreviated homocercal or gephyrocercal types of caudal fin.

PAIRED FINS

The paired fins, the pectorals and pelvics, correspond the forelimbs and the hind limbs respectively of the tetrapods. The pectoral fins are usually situated just posterior to the gill-opening. The position of the pectoral fins varies slightly in different fishes. But the position of the pelvic fins varies considerably in different forms. Both these paired fins are supported by *dermotrichia* (fin-rays) and *somactids* (radialia). In *Cladoselache*, a primitive extinct shark, the somactids are arranged parallel to one another and are termed as *orthostichous* type (Fig 5.58A). The *rachiostichous* type of fin skeleton (i.e., the somactids are represented by a jointed basal piece articulating with the girdle and provided with a posterior postaxial and an anterior preaxial [illegible]ials. The radials are attached to the b[illegible] piece.) is observed in *Ceratodus*. Such [illegible]af-like structure of the fin is called the [illegible]*pterygium*. In many fishes, particul[illegible]ry o[illegible] elasmobranchs, the fin-skeleton assumes a fan-like form and is described as the *rhipidoschous* type. The question of primitiveness of the archipterygium type of fin as advanced by Gagenbaur is challenged by Balfour. According to him the fin skeleton found in Cladoselache with parallel arrangement of somactids appears to be more convincing. The parallel somactids supporting the paired fins are possibly originated from the local specialisation of once parallel somactids of the continuous fin fold.

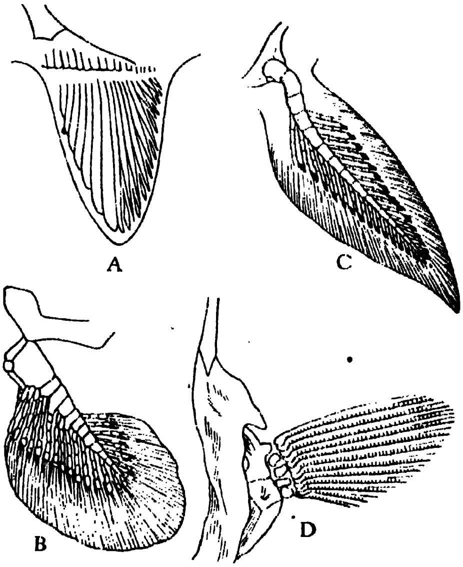


Fig. 5.58. Pectoral fins some fishes. A. *Cladoselache*. B. *Pleuracanthus*. *Neoceratodus*. D. *Gadus* (after Young).

Pectoral fins. The pectoral fins in the elasmobranchs are highly developed and are larger in size in comparison to that of bony fishes. In Skates and Rays, the pectoral fins become enormously developed on the sides of the body and head. These lobe-like pectoral fins act as the principal locomotor organs. In bony fishes, the pectoral fins are paddle-like and small. In many bony fishes the outer margin of the fin is provided with a stout spine. In some Cat-fishes, the pectoral spine is associated with a basal poison gland. The spines are defensive organs and in *Doras* and *Clarias* the pectoral spines also help in progression on land.

The pectoral fins are present in almost all the fishes except some of the Eels and Pipe fishes where the pectorals are wanting. The pectoral fins are always longer in speedy fishes but in the fishes of slow movement these are broad and round. *Neoceratodus* (Fig. 5.58C) possesses peculiar lobate leaf-like pectorals, while in *Lepidosiren* and *Protopterus*, the pectorals become extremely elongated and filamentous. In *Exocoetus* (flying fish) the pectoral fins have been extremely enlarged into the 'wings' and help to make short aerial excursion. In *Pantodon* another flying fish of African rivers, the pectorals are greatly elongated and beat rapidly during flight. In Frog-fishes, Sea-toads and Bat-fishes, the pectoral fins assume the appearance of "hands" and help to crawl on the bottom of the sea. The mud-skipper (*Periophthalmus*) makes a short excursion over marshy land and the pectoral fins are specialised for the purpose. The fin is membranous and is attached with a muscular stalk. In many fishes like *Polynemus*, *Latris*, some of the fin-rays supporting the pectoral fins are modified for sensory function. These fin-rays have drawn out into delicate filaments containing sense organs.

Pelvic fins. Like that of pectoral fins, the position and shape of the pelvic fins vary greatly in different fishes. The burrowing fishes usually lack the pelvic fins. In all the Eels, Pipe-fishes, the pelvic fins are lacking. In many bony fishes under the family Gadidae (Cods), the pelvic fins are reduced to filaments. In bony fishes, the pelvic fins may be abdominal (between the anal and pectorals) or thoracic (more or less below the pectorals) or jugular (in front of the pectorals) in position.

The conspicuous specialisation of the pelvic fins lies in their transformation into sucking disc for attachment with stones or any other objects. *Gastromyzon* possesses a large sucker and both the paired fins participate in the formation. In *Cyclopterus* (Lump-sucker) and *Liparis* (Sea-snail) similar sucking disc is present. Another remarkable modification of the pelvic fins is observed in the skates and rays where the distal part of the pelvic fin is modified into '*claspers*' (mixopterygia) in males.

DIGESTIVE SYSTEM

Fishes devour various types of food. Some of them feed exclusively on plant materials, others on animals and the rest are omnivorous. As a result of adaptation to different feeding habits, the digestive system becomes extremely modified.

The first part of the alimentary canal of the fish is designated as the buccopharynx which performs two functions: (1) collection of food and conveying them to the oesophagus and (2) respiration. In the predatory and the carnivorous fishes, viz., *Wallago attu*, *Channa punctatus*, *Notopterus chitala*, *Harpodon neherens*, the buccopharynx is armed with strong teeth. In herbivorous forms as examplified by *Labeo rohita*, *Cirrhina mrigala*, the buccopharynx is divided into two portions: (1) an anterior respiratory region and (2) a narrow posterior masticatory region. The plankton feeders may lack teeth in the buccopharynx. The nasal cavities are quite separate from the oral cavity excepting the choanichthyes. The oral cavity in fishes lacks glands excepting the simple mucous glands opening into it. The tongue in fishes is just a fold developed from the floor of the mouth cavity. The sensory receptors may be present in tongue which lacks muscles. Tongue may be absent in Rays.

The teeth are modified according to the purpose they are used. The location of teeth also varies greatly. Besides their normal location on the jaws, they may be present on tongue and on the hyoid arch. In most cases, dentition is polyphyodont, i.e., the fishes (particularly the sharks) do not keep the same set of teeth throughout life and there is constant replacement of the older functional teeth by the younger ones. The teeth are usually of acrodont (i.e., the teeth are linked basally with the jaws by fibrous membrane) and homodont types. The size and form of teeth exhibit great diversity in fishes. Simple conical teeth bearing longitudinal grooves and ridges are regarded to represent the primitive condition. Such teeth are present in extinct Crossopterygians and in *Latimeria*. Usually the teeth in fishes are conical projections, but may become modified into vertically flattened triangular plates as seen in sharks. In chimaeras and dipnoans, plate-like structures are formed by the fusion of several teeth for crushing molluscan shells. In majority of teleosts, the teeth are recurved to prevent the escape of slippery prey. The teeth may be large in size in deep-sea teleosts.

There is no distinct differen[illegible]on between oesophagus and stomach[illegible]ording to Barrington, the stomach is a le[illegible] portion of the oesophagus. Ori[illegible] was meant for the reception of [illegible]rly i[illegible]s of food and secondarily became modified to produce acid and the enzyme pepsin. The significance of the division of the stomach into a descending cardiac part and an ascending pyloric part is unknown. Stomach of various shapes may occur in different fishes. It is simple, straight and nonglandular in dipnoans. In elasmobranchs, the stomach is usually 'J'-shaped, but in teleosts the shape varies greatly. In teleosts the stomach is usually 'V'-shaped and the cardiac region is prolonged into a blind pouch. In deep-sea teleosts, it is highly distensible. In certain forms, e.g., *Cyprinus*, *Fundulus* and *Labrus* the stomach is totally absent. In many teleosts, *Hilsa*, *Mugil*, *Gadusia* the stomach becomes greatly thickened to form a gizzard-like structure for the trituration of food.

Presence of a spiral valve in the intestine in elasmobranchs is very common. Its arrangement may vary greatly in different forms. In some cases, the valve is not spiral, but rolled in the form a scroll. But the spiral valve is usually absent in osteichthyes excepting few forms like *Polypterus*. In many forms (*Lepisosteus*, *Amia*) it may be vestigial.

Many fishes possess pyloric caeca, but the number varies greatly. In *Somniosus*, there is a pair of pyloric caeca. In *Polypterus* there is only one pyloric caecum, but the number exceeds two hundred as seen in Mackerel. In some cases the pyloric caeca may be bounded together by connective tissue to form a compact mass. Histologically these caeca resemble the intestine and possibly increase the absorbtive area of the gut.

In elasmobranchs rectum terminates into a cloaca. A *rectal* or *digitiform gland* opens into the dorsal side of the rectum. But in most teleosts, anus opens separately to the outside. The rectal gland is absent in Actinopterygians, but seems to be present in *Latimeria*.

In fishes, the liver is a large bilobed organ. The gall-bladder is present in almost all forms excepting a few sharks. Elasmobranchs have a distinct pancreas, whereas in most teleosts, the endocrine part of the pancreas is encapsulated and separated from the exocrine part. Such isolated areas are designated as the principal islands.

RESPIRATORY SYSTEM

The fishes possess well-developed respiratory organs. The physiological process of respiration in different fishes is essentially similar to that of any higher vertebrate. The only difference in the respiratory process being the organs of respiration. Fishes are the primary aquatic vertebrates. They utilise the oxygen which remain dissolved mostly in water. A few fishes have the power to breathe air. In fishes the respiratory organs are the gills. Besides, some accessory respiratory structures for aerial respiration are encountered in some teleosts. In fishes where aerial respiratory structures have evolved, the gills in them play the subsidiary role. The gills constitute the efficient respiratory organs which are specially modified to utilise upto 80% of the oxygen dissolved in water that passes over the gills. Whereas in man, the lungs are capable of absorbing about 25% of oxygen from the air drawn into the pulmonary cavities. The efficiency of the gills as the respiratory organs in fishes depends upon two factors: (1) The structural organisation of the gills and the nature of vascularisation and (2) the gills are bathed by the continuous flow of water so that fresh oxygen is always brought in immediate contact with the gills.

Primary respiratory organs

The primary respiratory organs of the fishes are the gills.

Typical structure of gill. Typically each gill is a comb-like structure having series of gill-filaments attached to the gill-arch. Each gill-arch bears a double rows of gill-filaments. The surfaces of each gill-filament is thrown into numerous small folds which increase the sum total surface area of the gills for gaseous exchange. The respiratory area of the gill in fishes depends on the size and number of the gill-filaments. The development of respiratory area depends on the habit of the fishes. In fast moving forms the respiratory area is increased, while in slow moving or sedentary forms the respiratory area of the gill is lesser. The principle of gill respiration is basically similar in all the fishes but the structure, number and orientation vary considerably.

LOCATION OF GILLS

The side walls of the pharynx are perforated by a series of vertical slit-like openings. Each pharyngeal opening leads into a flattened *gill-pouch* which communicates to the exterior by the external *gill-slits*. The gill-pouches are separated by *interbranchial* *septa* which form the walls of the pouches. These septa bear *gill-filaments* on their opposite walls. The external gill-slits are situated on the side of the anterior end of the head between the eyes and the pectoral fins. The *gill-slits* are usually short, but in *Cetorhinus* (huge Basking shark) these are very large and extend from the upper to the lower surface of the body. The first slit-like aperture is designated the *spiracle* which is situated between the mandibular and hyoid arches. The second is called the hyoidean cleft which lies between the hyoid arch and the first branchial arch. The rest of the gill-slits are located between the posterior branchial arches. In most of the elasmobranchs, the number of the gill-slits is five on each side excluding the spiracle. But in some sharks the gill-slits may exceed the normal number of five pairs. *Hexanchus* bears six pairs and *Heptranchias* possesses seven pairs of gill-slits in addition to the spiracles.

In most of the elasmobranchs, particularly in the sharks, the gill-pouches open directly to the exterior by independent external gill-slits. In the sharks the partitions between the gill-slits are prolonged backward as the folds of skin to cover the external gill-slits. But in the bony fishes, the internal pharyngeal gill-slits are present, but these do not open independently to the exterior. All these open into a common branchial chamber which is covered by a movable *gill-cover* or *operculum.* Each branchial chamber opens to the exterior by a large slit-like aperture. The opercula of two sides may overlap or fuse ventrally. In some actinopterygians the degree of fusion becomes so great that the opercular openings become greatly reduced to small bilateral slits or round openings as observed in the Eels. The operculum is supported by broad, flat bony plates which may or may not be supported by slender branchiostegal rays on the ventral side. Amongst the elasmobranchs, the holocephalans are operculate. These forms represent a stage which stands midway between the rest of the cartilaginous fishes and the bony fishes. In these forms, the interbranchial septa are shorter than the true sharks and the gills are lodged in a common branchial chamber. The outer side of this chamber is bordered by a flap of skin resembling the operculum of the bony fishes. Each branchial chamber opens to the exterior by a single slit-like opening.

FUNCTION OF GILLS

The gills in fishes are mostly respiratory in function. Besides their respiratory role, the gills take part in the elimination of certain waste products and thus help in the maintenance of salt balance. Both fresh water and marine teleosts excrete nitrogenous waste products through the gills in the forms of ammonia and urea. *Cyprinus* (Carp) and *Carassius* (Gold fish) the gills excrete the nitrogenous waste products six to ten times more than that of kidneys.

TYPES OF GILLS

Based on location. Depending on the location of the gills, two types of gills are found in fishes: (1) *Internal gills.* When the gills lie inside the gill-pouches (sharks) or in the branchial chamber (in holocephalans and bony fishes). (2) *External gills.* The larval stages of many fishes develop external gills for respiration. The external gills are of two varieties depending on their development. These are: (*i*) *True external gills.* These are independent of the internal gills and developed as the modification of the integument. (*ii*) *Prolongations from the internal gills.* These gills are located outside the body, but these are nothing but the prolongations of the internal gill-filaments which lie on the outer side of the body. True external gills occur in the young stages of *Polypterus* and *Lepidosiren.* In the larvae of *Protopterus* and *Lepidosiren*, four pairs of small external gills are present. With the attainment of adulthood, the external gills in these forms are lost except Protopterus where vestiges of the external gills persist even in adult. In young Polypterus (Bichir) a pair of leaf-like external gills is present just above the gill opening.

The external gills of the second category are found in the embryo of some selachians and some oviparous bony fishes. In the selachian embryos long filamentous external gills develop from the walls of the gill-slits and project out through the external gill-slits. These filamentous structures help in respiration because the sea water circulates through these structures. In the viviparous selachians, these structures also help to absorb nutrient. The external gills observed in the youngs of some egg laying bony fishes (i.e., *Gymnarchus*, *Clupisdis* and many others) are respiratory in function. In *Gymnarchus*, slender filaments from the internal gills project beyond the opercular edge and function as the external gills.

Based on structure. Based on the structure and function, four types of gills are encountered in fishes. These are: *hemibranch*, *pseudobranch*, *holobranch* and *lophobranch*. As discussed earlier, the gill-pouches are separated by interbranchial septa. The anterior and posterior walls of each septum bear series of gill-filaments. Each series of gill-filaments on one side of the interbranchial septum constitute the *hemibranch* or half gill. The *pseudobranch* is a modified form of the hemibranch. The term pseudobranch is referred to the hemibranch which has lost the original respiratory function. A *holobranch* or complete gill is composed of two hemibranchs, i.e., a holobranch consists of an interbranchial septum (may be reduced in advanced fishes) with series of vascular gill-filaments developing on its anterior and posterior walls. Another peculiar type of gill is observed in Sea horses and Pipefishes where the gill-filaments become greatly reduced to form rosette-like tufts. These tufts are small and are attached to the greatly reduced gill-arches. Such types of gills are called the *tuft gills* or *Lophobranchs*.

FATE OF INTERBRANCHIAL SEPTA

The interbranchial septa in the primitive fishes are thick and contain tough fibrous tissue. These are supported by many cartilaginous movable segments which constitute the gill-arches. The gill-arches are situated at the inner side of the septa. Each arch appears like a half-hoop. The lowest pieces of the gill-arches almost join with the counterparts of the opposite and thus support the inner side of the pharynx like series of girders. The interbranchial septa show the tendency towards reduction in course of evolution (Fig. 5.59). In selachians, the interbranchial septa are arranged in such a fashion that a series of independent gill-slits are produced. In these forms the interbranchial septa are larger than the rows of gill-filaments. The interbranchial septa project backward as folds to cover the gill-slits. This condition represent the primitive condition amongst the fishes. But in the remaining fishes these septa become reduced to a varying degree. In chimaeras, the interbranchial septa are slightly shorter than the gill-filaments and the gill-filaments project a little beyond the outer edges. In the primitive bony fishes represented by Sturgeons (*Acipenser*) the septa become shorter and extend upto the midway. This condition is also observed in *Labeo rohita* and *Hilsa ilisha*, but in the other bony fishes the septa become progressively shorter as seen in Salmon, *Rita rita*, *Channa striatus*, etc. The condition of the interbranchial septa in Sturgeons exhibit a transitional stage between the chondrichthyan and teleostean conditions. The rows of gill-filaments or the two sides of the septum are independent of one another but in *Labeo rohita*, the adjacent rows of gill-filaments are fused at the tips and the bases so that a narrow slit-like aperture is left between these rows of gill-filaments.

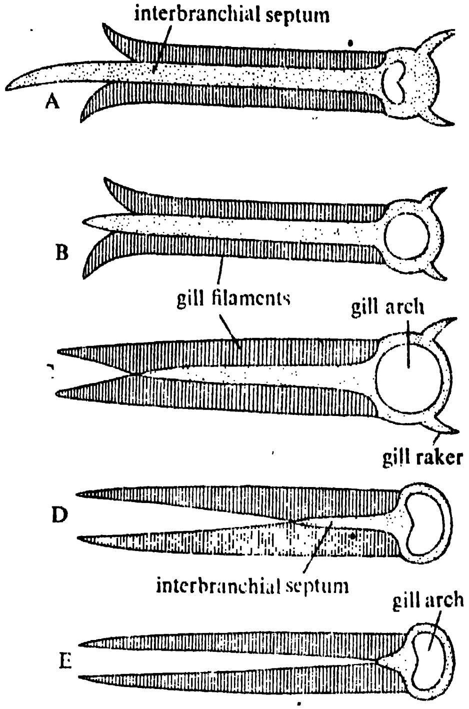


Fig. 5.59. Showing the fate of the interbranchial septum in different fishes. A. Typical selachian. B. Chimaera. C. Sturgeon. D & E. Teleosts.

FATE OF SPIRACLES

The spiracle is the slit-like aperture between the mandibular and hyoidean arches. This structure becomes subsequently modified in different fishes. In the sharks, the spiracles are present. The anterior side of the spiracular cleft bears spiracular gill composing of a number of gill-filaments. But in most of the fishes the spiracular gill is represented by a *rete mirabile* or network of blood vessels called the pseudobranch. The pseudobranchs, with all probabilities, are the organs for special sense. In skates and rays, the spiracles are highly developed and are provided with movable valves. The external gill-slits are located ventrally and during resting on the sandy bottom, there is every chance of the entry of sand particles inside the gill-pouches along with the respiratory water current. So to prevent the clogging up the gill-filaments by the introduction of foreign particles, these fishes inhale water through the spiracles and expel it by way of the gill-slits. The spiracular openings are closed in adult holocephalians, although these are present in the larval stage. There is no evidence of the existence of pseudobranch in the spiracular opening. In sharks, the spiracles retain a few gill-filaments in adult stage.

In bony fishes, the spiracles are mostly absent, although spiracular pouches may develop. *Amia* and *Lepisosteus* lack the spiracle and the spiracular pouch is greatly reduced. In *Acipenser*, the spiracle and tube-like spiracular pouch are present. *Scaphirhynchus* lacks a spiracle. *Polypterus* possesses a wide spiracle and a cellular ridge separates the spiracular pouch and the hyobranchial groove. In Crossopterygians, the spiracles are absent. In Latimeria, the spiracular pouch is very deep, but in the lungfishes, the spiracular pouch is greatly reduced.

GILL-RAKERS

The gill-rakers are specially developed on the inner edge of gill-arches. The gill-rakers are modified dermal denticles and are arranged in double rows. The development of gill-rakers in fishes depends on the particular mode of feeding. In the fishes which devour minute organisms, the gill-rakers are highly developed. During swimming there is every chance of entering the small creatures through the internal gill-slits and thus the gill-filaments may either be damaged or clogged. These are avoided by the development of the gill-rakers. The gill-rakers form a sort of sieving apparatus which strains the water that bathe the gill-filaments.

The structure of the gill-rakers varies greatly in different fishes (Fig. 5.60). The herring like fishes (*Hilsa, Gadusia, Gonialosa, Notopterus*) are plankton feeders and the gill-rakers become slender and extremely elongated. These rakers form a close-set strainer. In many other filter feeders, the primary gill-rakers bear secondary and tertiary branches and thus appear like a fine gauze. In *Esox* (Pike) the gill-rakers are reduced to bony knobs which prevent the entry of larger particles. The structure and number of gill-rakers vary considerably even within the closely related forms.

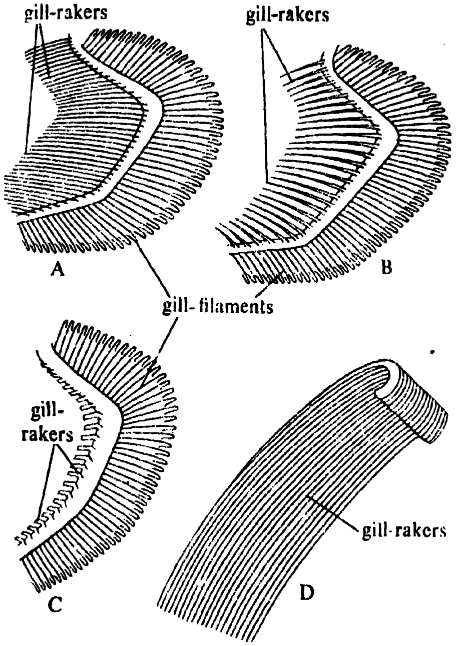


Fig. 5.60. Showing the gill-rakers in different fishes. A. *Alosa fallax*. B. *Alosa alosa*. C. *Perca fluviatilis*. D. Isolated gill-rakers of *Cetorhinus maximus*.

In adult *Alosa alosa*, the lower limb of the arch bears about eighty gill-rakers, whereas, *Alosa fallax* possess only thirty. The gill-rakers in *Cetorhinus* (Basking shark) and *Rhincodon* (Whale shark) measure about 10–12 cm in length. These become flattened to form a closely set structure. This structure recalls the ***baleen plate*** of whalebone of whales in structure and function. The gill-rakers are generally absent in other sharks. In crossoptergians the gill-rakers are rudimentary.

Gills in different fishes

The gills in fishes are basically similar. In elasmobranchs, the gills are mostly hemibranchs, whereas in the teleosts the gills are mostly holobranchs. The vestigial mandibular gills (pseudobranchs) are present in some fishes. Most of the sharks possess on each side a mandibular pseudobranch, a hyoidean hemibranch and four, five or six holobranchs. In holocephalans, the mandibular pseudobranch is lacking, but the hyoid arch has a posterior hemibranch. The first, second and third gill-arches bear holobranchs whereas the fourth bears a hemibranch. In sharks, each gill arch contains one afferent and two efferent vessels, while in holocephalans only one efferent vessel is present.

Amongst the Osteichthyes, the actinopterygians possess on each side, a mandibular hemibranch or pseudobranch, four holobranchs (on the first, second, third and fourth gill-arches). In some forms, a hemibranch may be present. A hyoidean hemibranch may be lacking in some cases. In crossopterygians, the nature of the gills is slightly different. There is no existence of mandibular pseudobranch in Latimeria, although small hyoidean hemibranchs may be present. Like that of other actinopterygians, there are four pairs of holobranchs in Latimera. But the fifth gill-arch is devoid of any gill. The dipnoans resemble Latimeria in gill arrangement. Neoceratodus contains a hyoidean hemibranch, holobranch on the fourth and fifth arches. The sixth gill-arch bears an anterior hemibranch. In Lepidosiren, the second, third and fourth gill-arches have holobranchs. The hemibranchs are lacking.

Pseudobranchs. The pseudobranchs lack the respiratory function. The pseudobranchs becomes greatly reduced in different fishes. In Trout, the pseudobranch retains the characteristic comb-like appearance. The gill-filaments become extremely reduced and are covered by the pharyngeal epithelium in case of Perch. In the Cod, the pseudobranch becomes completely covered in the pharyngeal epithelium to form a gland like organ called the *vaso-ganglion* or *rete mirabile.* Although the pseudobranchs are embedded deeply in the pharyngeal tissue, these structures retain the fine structure of the gill-tissue. In *Amia,* the pseudobranchs are reduced and covered by the pharyngeal mucous epithelium. In *Catla catla,* the pseudobranch is attached to the anterior gill. The pseudobranchs may be free or may be covered by mucous epithelium. These receive oxygenated blood from the dorsal aorta. The pseudobranchs lack respiratory function in adult and subserve other functions. The mandibular hemibranchs usually help to close the spiracles and get oxygenated blood. These structures may (*i*) increase the oxygen concentration in the blood going to the brain or (*ii*) regulate the blood pressure in the ophthalmic artery or (*iii*) act as endocrine organ. The pseudobranchs contain largely the acidophilic cells. In *Lepisosteus* the mandibular pseudobranch remains in close contact with the hyoidean hemibranch and gets blood from the afferent hyoid artery and the efferent artery from the first arch. *Acipenser* resembles *Lepisosteus* except that the mandibular pseudobranch and hyoidean hemibranch lack connection. The pseudobranchs of *Amia* lack direct afferent or efferent blood connection. The pseudobranchial vessels join the orbital and ophthalmic vessels. *Polypterus* lacks mandibular pseudobranchs.

Hyoidean hemibranchs. The hyoidean hemibranchs are present in most of the fishes. In the sharks, hyoidean hemibranchs are present. In selachians, the hyoidean hemibranchs have either disappeared or represented by rudiments. In the holocephalans, hyoidean hemibranchs remain attached with the operculum. But in most of the actinopterygians, the hyoidean hemibranchs are absent. In *Acipenser, Lepisosteus* and *Polyodon* these gills are present, but *Amia* lacks the hyoidean hemibranchs. In *Scaphirhynchus,* these hemibranchs are greatly reduced. *Polypterus* lacks both the mandibular pseudobranchs and hyoidean hemibranchs. The absence of these gills may possibly be resulted due to the conversion of the swim-bladder into the air-breathing 'lungs'. Amongst the crossopterygians, hyoidean hemibranchs are present in all the living forms except Lepidosiren. In Latimeria the hyoidean hemibranchs are small.

BLOOD SUPPLY TO THE GILLS

The gills are well-supplied with blood vessels. The flow of blood and the water current pass one another in opposite directions. This arrangement ensures efficient exchange of dissolved substances between the two fluids. If the direction of flow of the two fluid is experimentally reversed, the uptake of oxygen falls from 50% to 9%. As already discussed, the gill-filaments are provided with folds which permit the blood to come in intimate contact with the water for gaseous exchange.

The gills are composed of primary gill-filaments which produce numerous secondary folds (filaments). Each secondary gill-filament has a central core of vascular tissue overlined by a thin layer of connective tissue and mucous epithelium. The vascular central core contains capillary networks and supporting *Pilaster* cells. In most of the teleosts, each gill-arch contains one afferent and one efferent branchial vessel. But in *Labeo rohita*, *Clarias batrachus*, *Trichogaster fasciatus*, *Anabas testudineus* and many others, two efferent vessels are present in each gill-arch. Amongst the cartilaginous fishes, each gill-arch contains one afferent and bilateral efferent vessels. But in the holocephalans only one efferent vessel is present. In lung-fishes each gill-arch contains two efferent arteries.

In a typical teleost, each gill-arch contains an afferent branchial and an efferent branchial vessel. Each afferent branchial gives off primary afferent vessels to the primary gill-filaments. Each primary afferent vessel divides into a number of secondary and tertiary branches to the secondary gill-filaments. The afferent vessels break up into capillaries in the secondary gill-filaments. These capillaries join and the blood is carried to the primary efferent vessel. The primary efferent vessels run along the margin of the primary gill-filaments and get secondary efferent vessels from the secondary gill-filaments. Exchange of gases takes place while the blood passes through the capillaries and the oxygenated blood from the gill-filaments is collected in the main efferent branchial vessels.

Most of the fishes cannot survive out of water because of the failure of respiring in air. But there are many fishes which do survive out of water for a considerable period of time. This is possible by the development of certain specialised organs usually called the accessory respiratory organs.

Accessory Respiratory organs

All other respiratory organs in fishes except the gills are designated as the accessory respiratory organs (Fig. 5.61). These organs are developed in addition to the gills and develop as the adaptation to the particular environmental condition. The development of accessory respiratory organs is encountered mostly in the fresh water fishes of tropical region and occurs very rarely in marine forms. Sometimes the fishes of the tropical fresh water and streams of the hills, develop accessory respiratory organs to meet extra demand of oxygen, because depletion of oxygen occurs during summer as the water level falls to a considerable degree. Prolonged drought forces some fishes to develop some devices to live out of water for a short period of time. In some fishes, the metabolic rate is so high that dissolved oxygen in water becomes insufficient. To overcome these adverse situations, accessory respiratory organs functionable in aquatic and/or aerial environment have been developed in fishes. So the development of such structures is essentially adaptive in nature.

The accessory respiratory structures in fishes are discussed under two broad categories: *Aerial accessory respiratory structures* and *aquatic accessory respiratory structures*. The respiratory organs of the first category are very important. In many fishes to supplement the normal function of the gills, a few accessory aquatic respiratory structures has been developed to increase the intake of more oxygen from the water.

Suprabranchial organ. The suprabranchial organ is a specialised type of respiratory structure encountered in *Clarias* (Fig. 5.61A). It has a complex structural organisation and consists of the following portions: (1) An elaborate tree-like structure growing from the upper end of the second and fourth gill-arches of either side. This *dendritic* organ is composed of numerous terminal knobs, each has a core of cartilage covered by vascular membrane. Each exhibits eight folds which suggest that one such knob is formed by the coalescence of eight gill-filaments. (2) A pair of highly vascularised *suprabranchial chambers* within which the tree-like structures are contained. The suprabranchial chambers are developed as the vascularised diverticula of the branchial chamber. (3) The entrance of the suprabranchial chamber is guarded by 'fan'-like structures which are developed by the fusion of the adjacent gill-filaments of the dorsal side of the gill-arches. The suprabranchial organs (like the gills) are lined by a thin outer epithelial layers with intercellular spaces separated by the pilaster cells. The organs and the suprabranchial chambers are supplied by afferent and efferent blood vessels from the gill-arches.

The suprabranchial organs help to breathe in air. These fishes come to the surface of the water and gulp air into the suprabranchial organs. Atmospheric air from the pharyngeal cavity is taken into the suprabranchial chamber by an inhalant aperture located between the second and third gill-arches. After the gaseous exchange the air from the said chamber expels into the opercular cavity by the gill-slit between the third and fourth gill-arches. The fan-like structures present in the second and third gill-arches help to intake the air while the expulsion of the air from the suprabranchial chamber is caused by the contraction of its wall. Thus the suprabranchial chamber and its contained organs function as the 'lung'.

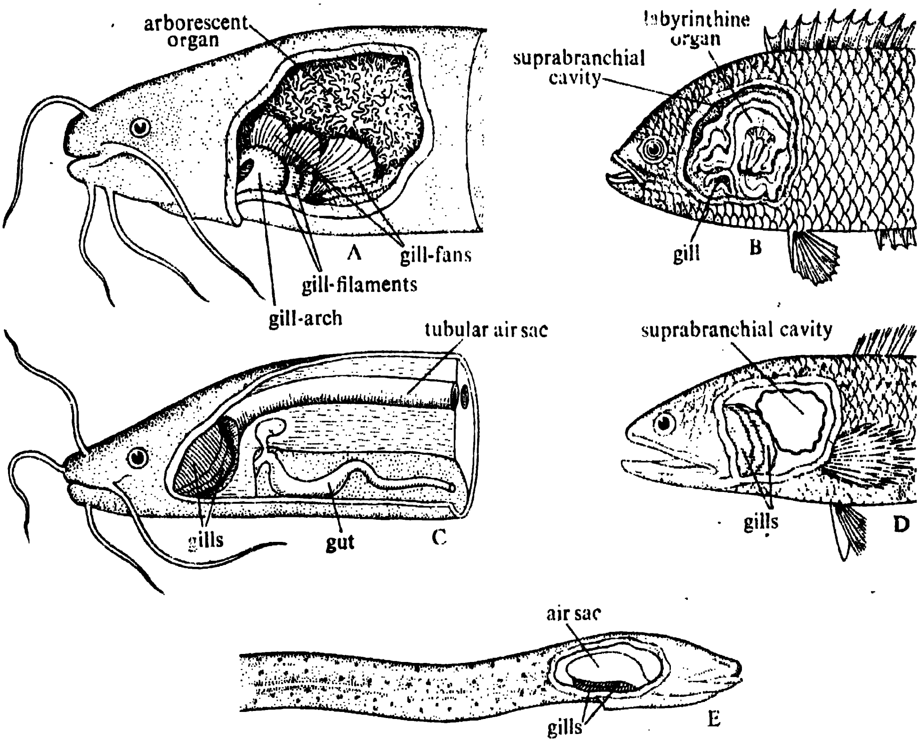


Fig. 5.61. Accessory respiratory organs in airbreathing teleosts. A. *Clarias batrachus*. B. *Anabas testudineus*. C. *Hetropneustes fossilis*. D. *Channa punctatus*. E. *Amphipnous cuchia*.

Branchial outgrowths. In climbing perch (*Anabas testidineus*) there are two spacious sac-like outgrowths from the dorsal side of the branchial chambers (Fig. 5.61B). The epithelium lining these outgrowths are highly vascular and becomes folded to increase the respiratory area. Each chamber contains a characteristic rosette-like organ. This organ develop from the first epibranchial bone and consists of a number of shell-like concentric plates. The margins of the plates are wavy and the plates are covered with vascular gill-like epithelium. Each branchial outgrowth communicates freely not only with the opercular cavity but also with the buccopharyngeal cavity. Air enters into the outgrowth by way of the buccopharyngeal opening and goes out through the external gill-slits. The entrance is controlled by the valves.

The fish can breathe in air by the help of these organs. These fishes have the habit of migration from one pond to the other. Their overland progression is peculiar and assisted by the operculum and the fins. Each operculum bears sharp spines at the free edge. During travelling the opercula alternately spread out and fix to the ground by the spines and get the forward push from the pectoral fins and the tail. The proverb that the fish can climb the trees seems to be erroneous. The climbing-perches are found in the branches of palm or other trees which are possibly brought there by the kites or crows while these fishes migrate over the land.

Pharyngeal diverticula. In the Snake-headed fishes and Cuchia eels, the accessory respiratory organs are relatively simplified. These fishes can survive prolonged drought and their air breathing habit enables them to remain out of water for some time. In both the group of fishes, the pharynx gives a pair of sac-like diverticula for gaseous exchange.

In *Channa*, the accessory respiratory organs are relatively simpler and consists of a pair of air-chambers (Fig. 5.61D). These are developed from the pharynx and not from the branchial chamber as seen in others. The air-chambers are lined by thickened epithelium which is highly vascularised. The air-chambers are simple sac-like structures and do not contain any structure. These chambers functions as the lung-like reservoirs. In *Channa striatus* the vascular epithelium lining the chambers become folded to form some alveoli. The gill-filaments are greatly reduced in size.

In Cuchia (*Amphipnous cuchia*) the accessory respiratory organs consist of a pair of vascular sac-like diverticula from the pharynx above the gills (Fig. 5.61E). These diverticula open anteriorly into the first gill-slit. These diverticula function physiologically as the lungs. The gills are greatly reduced and a few rudimentary gill-filaments are present on the second of the three remaining gill-arches. The third gill-arch is found to bear fleshy vascular epithelium.

In *Periophthalmus*, a pair of very small pharyngeal diverticula is present which are lined by vascular epithelium.

Pneumatic sacs. In *Heteropneustes fossilis* a pair of tubular pneumatic sacs, one on each side of the body, acts as the accessory respiratory organs. These long tubular sacs arise as the outgrowths from the branchial chamber and extend almost upto the tail between the body musculature near the vertebral column (Fig. 5.61C). In *Saccobranchus*, similar tubular lung-like outgrowths of the branchial chamber extend back into the body musculature.

Buccopharyngeal epithelium. The vascular membrane of buccopharyngeal region in almost all the fishes helps in absorbing oxygen from the water. But in mudskippers (*Periophthalmus* and *Boleopthalmus*) the highly vascularised buccopharyngeal epithelium helps in absorbing oxygen directly from the atmosphere. These tropical fishes leave the water and spend most of the time skipping or 'walking' about through dampy areas particularly round the roots of the mangroove trees. The old idea that the mudskippers use the vascular tail as the respiratory organ is not supported by the recent Icthyologists.

Integument. Eels are recorded to make considerable journey through damp vegetation. The common eel, *Anguilla anguilla* can respire through the integument both in air and water. In *Amphipnous cuchia* and mudskippers, the moist skin subserves respiration. Many embryos and larvae of fishes respire through the skin before the emergence of the gills. The median fin fold of many larval fishes is supplied with numerous blood vessels and helps in breathing. The highly vascular opercular fold of Sturgeon and many Cat fishes serves as the accessory respiratory structure.

Gut epithelium. The inner epithelium of the gut essentially helps in digestive process. But in many fishes the gut becomes modified to subserve respiratory function. *Cobitis* (giant loach of Europe) comes above the water level and swallows a certain volume of air which passes back along the stomach and intestine. In *Misgurus fossilis*, a bulge just behind the stomach is produced which is lined by fine blood vessels. This bulge acts as the reservoir of air and functions as the accessory respiratory organ. After the gaseous exchange, the gases are voided through anus. In certain other fishes, *Callichthyes*, *Hypostomus* and *Doras* the highly vascular rectum acts as the respiratory organ by sucking in and giving out water through the anus alternately. In these fishes the wall of the gut becomes modified. The wall becomes thin due to the reduction of the muscular layers.

Outgrowths of Pelvic fin. In *Lepidosiren* delicate vascular outgrowths on the pelvic fins are respiratory in function. These outgrowths develop in male during breeding season and act as the accessory respiratory organs to compensate aerial respiration at that particular period of time.

Swim-bladder acts as lung. Swim-bladder is essentially a hydrostatic organ but in some fishes it functions as the 'lung'. In Amia and Lepisosteus, the wall of the swim-bladder is sacculated and resembles lung. In Polypterus the swim-bladder is more lung-like and gets a pair of pulmonary arteries arising from the last pair of epibranchial arteries. The swim-bladder in dipnoans resembles strikingly the tetrapod lung in structure as well as in function. In *Neoceratodus*, it is single, but in *Protopterus* and *Lepidosiren* it is bilobed. The inner surface of the 'lung' is increased by spongy alveolar structure. In these fishes the 'lung' is mainly respiratory in function during aestivation because the gills become useless during this period. Like that of Polypterus, the 'lung' in dipnoans gets the pulmonary arteries from the last epibranchial arteries.

The cause of emergence of the accessory respiratory structures in fishes in addition to the primary respiratory organ is very difficult to interprete. There are two contrasting views regarding the origin of the aerial accessory respiratory structures. First view: Some fishes have the natural instinct to make short excursion to the land from the primal aquatic home. To remain out of water, the development of certain devices to breathe in air becomes necessary. Second view holds that the fishes are forced to ascend on land when the oxygen content of the water falls to a considerable extent. The fishes in that particular condition of life gulp in atmospheric air from the land and pass it into the accessary respiratory structures. If they are prevented by mechanical barriers to come to surface, the fishes will die of suffocation. This habit of swallowing bubbles of air is observed in many bony fishes, especially living in shallow water which dries up periodically or becomes foul by the decomposition of aquatic vegetation. As a consequence of the air-breathing habit over a considerable span of time, the fishes have developed specialised accessory respiratory organs in addition to the gills. Most of such structures encountered in the fishes assume the shape of reservoir of air originating either from the pharyngeal or branchial cavities. In extreme cases the reservoir may house special structure for gaseous exchange. However, the development of such accessory respiratory organs is essentially adaptive in nature to meet the respiratory need and thus enable the fishes to tolerate oxygen depletion in water or to live on land over a varying period of time. The development of the accessory respiratory organs depends on the ability to remain out of the water.

SWIM-BLADDER AND WEBERIAN APPARATUS

In most of the fishes a characteristic sac-like structure is present between the gut and the kidneys. This structure is called by various names, viz. Swim-bladder, or gas-bladder or air-bladder. In our present discussion the name of the bladder is followed as the swim-bladder to avoid confusion. The swim-bladder occupies the same position as the lungs of the higher vertebrates and is regarded as homologous to the lungs. It differs from the lungs of higher forms mainly in origin and blood supply. The swim-bladder arises from the dorsal wall of the gut and gets the blood supply usually from the dorsal aorta, while the vertebrate lung originates from the ventral wall of the pharynx and receives blood from the sixth aortic arch. The swim-bladder is present in almost all the bony fishes and functions usually as a hydrostatic organ. Starting as a very insignificant cellular extension from the gut, the swim-bladder in fishes leads the whole group through an evolutionary channel.

Development of swim-bladder. Opinions differ as regards the development of swim-bladder in fishes. In teleosts, it originates as an unpaired dorsal or dorsolateral diverticulum of the oesophagus. It starts as a small pouch budded off from the oesophagus. The diverticulum with an opening in the oesophagus becomes subsequently divided into two halves. Of these two, the left one often atrophies except in a few primitive forms. The right half becomes well-developed and takes a median position. In dipnoans and Polypteridae, the swim-bladder is modified into the 'lungs' and originate as the downgrowths from the floor of the pharynx. These outgrowths have been rotated around the right side of the alimentary canal to occupy the dorsal position. As the consequence of shifting of the position, the original right 'lung' becomes the left one. Spengel advocates the view that the swim-bladder in fishes originates from the posterior pair of the gill-pouches, but definite embryological evidence in support of this idea is lacking.

Basic structure of swim-bladder. The swim-bladder in fishes varies greatly in structure, size and shape. It is essentially a tough sac-like structure with an overlying capillary network. Beneath the capillary system there is a connective tissue layer called the *tunica externa*. Below this layer lies the *tunica interna* consisting primarily of smooth muscle fibres and epithelial gas-gland. The swim-bladder may be composed of one or two or many chambers. In teleosts, the swim-bladder lies below the kidneys, between the gonads and above the gut. The connection with the oesophagus may be retained throughout life or may be lost in adult. Biot (1807) and Morean (1876) have shown that the gas secreted by the swim-bladder is mostly oxygen. Nitrogen and little quantity of carbondioxide are also present.

Types of swim-bladder. Depending on the presence of the duct (*ductus pneumaticus*) between the swim-bladder and the oesophagus, the swim-bladder in fishes can be divided into two broad categories: *Physostomus* and *Physoclistous* types. Depending on the condition of the swim-bladder, the teleosts are classified by older taxonomists into two groups Physostomi and Physoclisti. A transitional condition is observed in eels.

Physostomous condition. As stated earlier the swim-bladder develops from the oesophagus. When the ductus pneumaticus is present between the swim-bladder and the oesophagus, the swim-bladder is called the physostomous type (Fig. 5.62A). A vessel emerging from the coeliacomesenteric artery supplies the swim-bladder and the blood from it is conveyed to the heart through a vein joining the hepatic portal vein. This condition is observed is bony gonoid fishes, the dipnoans and soft-rayed teleosts.

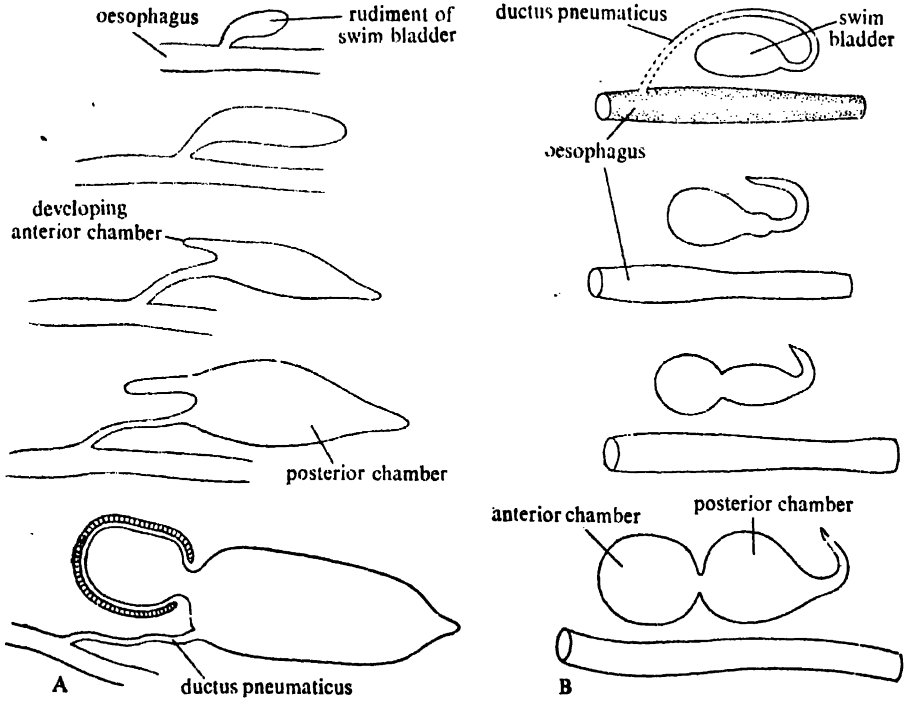


Fig. 5.62. Showing the derivation of the swim-bladder of the fishes from the gut. A. Stages of formation of physostomous type of swim-bladder in *Catostomus*. B. Stages of formation of the physoclistous type of swim-bladder.

Physoclistous condition. In this condition the ductus pneumaticus is either closed or atrophied (Fig. 5.62B). This type of swim-bladder is observed in spiny-rayed fishes. In this type of swim-bladder, there lies an anteroventral secretory *gas gland* (containing retia mirabilis) and a posterodorsal gas absorbing region called the *oval.* The oval develops out of the degenerating ductus pneumaticus. The rete mirabilis of the gas gland, the oval and the walls of the bladder are supplied by the coeliacomesenteric artery and also by the arteries from the dorsal aorta. But the blood from the different parts of the swim-bladder is returned by two routes. The blood from the gas gland is returned to the heart by the hepatic portal vein, while from the rest of the bladder by the posterior cardinal veins. The bladder, specially the gas gland, gets the lateral branches from the vagus, while the oval is innervated by the sympathetic nerves.

Transitional condition. In eel (*Anguilla*), a transitional condition between the physostomous and physoclistous type is present. The swim-bladder retains the ductus pneumaticus which becomes enlarged to form a separate chamber containing the oval (Fig. 5.63C). The gas glands are also present. The swim-bladder is supplied with the blood through a branch from the coeliacomesenteric artery while the blood is returned to the heart by a vessel joining the postcardinal vein. The condition represents an intermediate stage when a physostomous condition is on the verge of transformation into the physoclistous state.

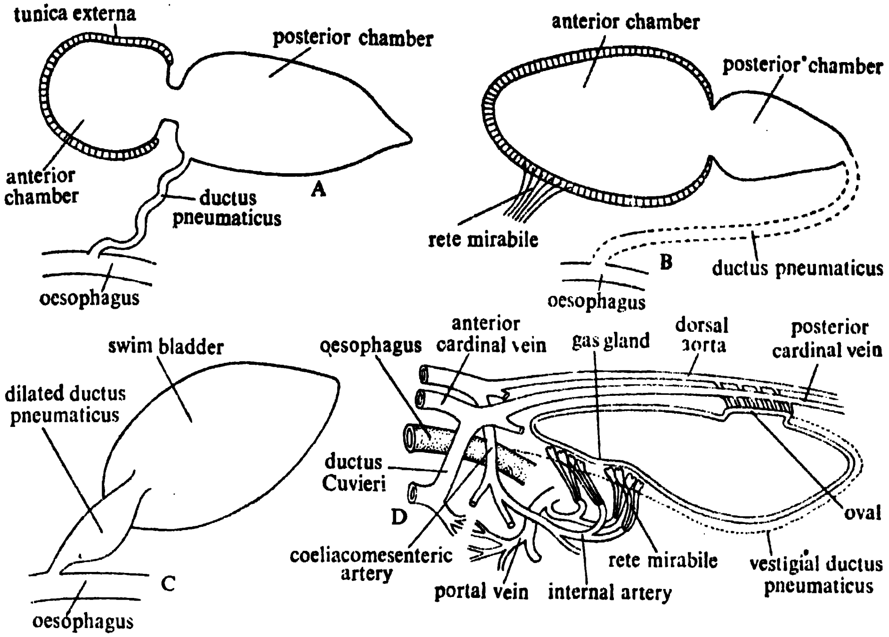

tunica externa
posterior chamber
anterior chamber
ductus pneumaticus
A
oesophagus
anterior chamber
posterior chamber
rete mirabile
B
ductus pneumaticus
oesophagus
swim bladder
dilated ductus pneumaticus
C
oesophagus
oesophagus
anterior cardinal vein
gas gland
dorsal aorta
posterior cardinal vein
ductus Cuvieri
D
oval
coeliacomesenteric artery
portal vein
internal artery
rete mirabile
vestigial ductus pneumaticus

Fig. 5.63. Variations in the structure of swim-bladder in fishes. A. *Catostomus*. B. A typical physoclistous type of swim-bladder with anterior and posterior chamber. C. Transitional swim-bladder in eel. Note the dilatation of the ductus pneumaticus. D. A physoclistous swim-bladder with oval. Note the circulatory pathways.

Swim-bladder and its modifications

In fishes a great diversity in size, shape and function of the swim-bladder is observed. In elasmobranchs, bottom dwelling and deep-sea teleosts the swim-bladder is absent in adult but a transitory rudiment during development may be present. In flat fishes (Pleuronectidae) swim-bladder is present in the early life when the animals maintain a vertical position. As they tip over one side and assume the lazy adulthood the swim-bladder becomes atrophied.

In elasmobranchs, the swim-bladder is represented by the transitory rudiment in the embryonic stages. Miklucho-Maclay (1867) has observed a rudimentary dorsal diverticulum from the foregut in the embryos of *Squalus*, *Mustelus* and *Galeus*. In many fishes, viz., *Heptranchias*, *Scyllium*, *Squatina*, *Pristiurus*, *Carcharius* and many Rays, small pits are recorded in the oesophageal wall. Wassnezow (1932) has observed one to six similar oesophageal pits in *Pristiurus*, *Torpedo* and *Trygon*. These pits are located posterior to the fifth pouch. In sharks the swim-bladder is absent in adult, but a hint of a rudimentary swim-bladder is observed in the embryonic development. But almost all the teleosts possess the swim-bladder and extreme modifications of the same are encountered because of adaptation to the different modes of living.

Modifications of Physostomous condition. The typical physostomous pattern becomes modified in different fishes and the basic trends are: (1) the formation of paired sacs and (2) the gradual acquisition of two chambers—an anterior and a posterior.

The swim-bladder in *Polypterus* (Fig. 5.64 A, B) represents the primitive condition. It is a bilobed sac with two unequally developed lobes. The left lobe is shorter and

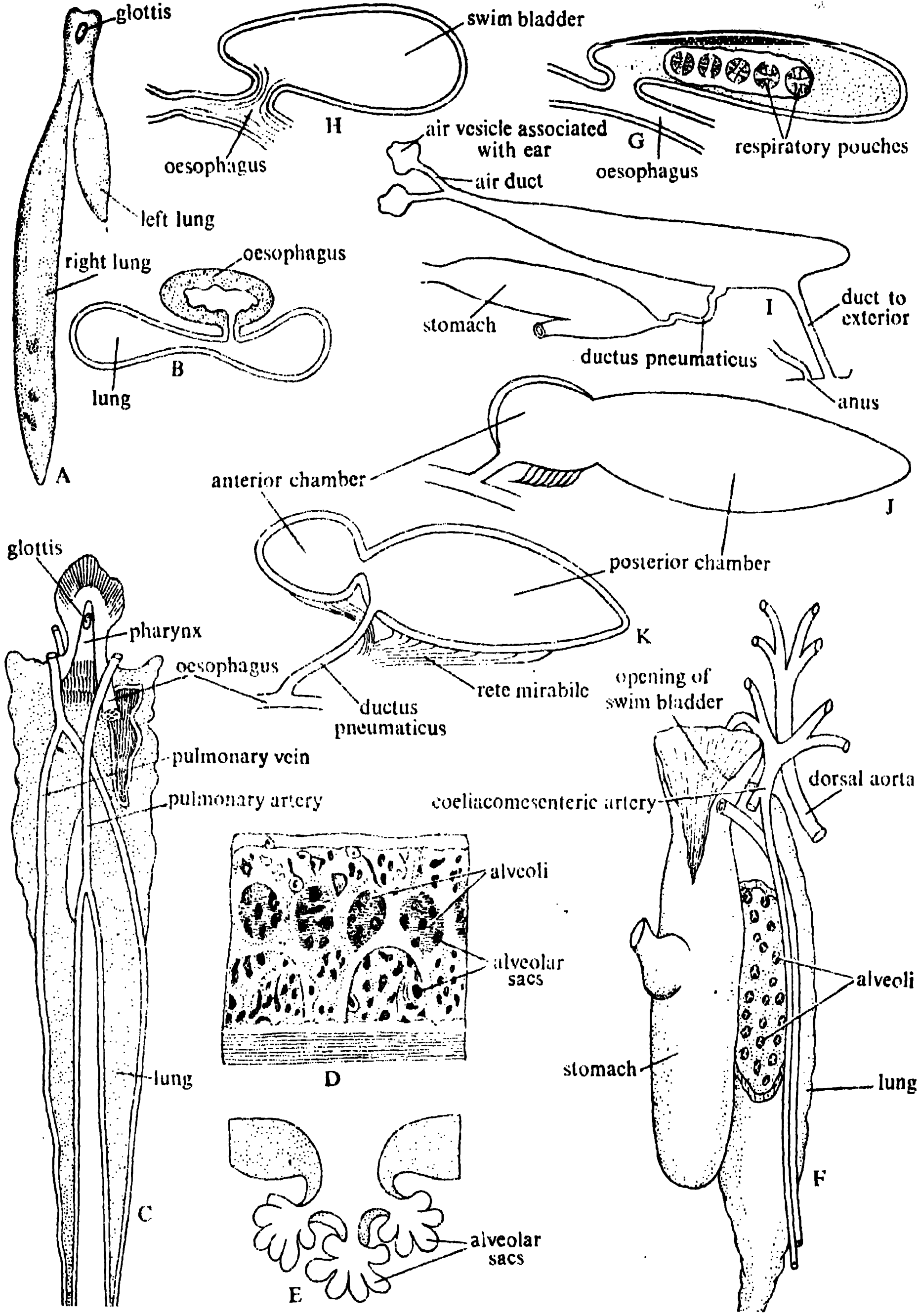

glottis
swim bladder
left lung
oesophagus
H
respiratory pouches
G
oesophagus
air vesicle associated with ear
air duct
right lung
oesophagus
B
lung
A
stomach
ductus pneumaticus
I
duct to exterior
anus
anterior chamber
J
posterior chamber
glottis
pharynx
oesophagus
pulmonary vein
pulmonary artery
K
rete mirabile
ductus pneumaticus
opening of swim bladder
coeliacomesenteric artery
dorsal aorta
alveoli
alveolar sacs
D
lung
alveoli
stomach
lung
C
F
alveolar sacs
E

Fig. 5.64. Variations in the structure of swim-bladder in fishes (Contd.). A. Swim-bladder in *Polypterus*. The swim-bladder is modified as 'lung'. Note that the left 'lung' is smaller in size. B. Sectional view of the swim-bladder and oesophagus in *Polypterus* showing their relationship.C. Swim-bladder of *Protopterus*. The swim-bladder if modinified to the 'lung'. D. A portion of the internal cavity of the 'lung' of *Protopterus* is enlarged to show the location of the alveoli. E. Showing a single alveolus of the 'lung' of *Protopterus*. F. Swim-bladder of *Gymnarchus* and its relative position. The swim-bladder is regarded the 'lung'. A portion of the 'lung' is removed to show the alveoli. G. Swim-bladder of *Amia* and *Lepisosteus*. A portion is cut opened to show the internal structures. H. Swim-bladder of *Acipenser*. I. Swim-bladder of *Clupea harengus*. J. Swim-bladder of *Esox*. K. Swim-bladder of a Cyprinoid fish (after various sources).

the right lobe is longer. The bilobed sac opens on the floor of the pharynx through a slit-like glottis. The glottis is provided with muscular sphincter. The internal lining of the bladder is smooth and partly ciliated. The lack of alveolar sacculations and the presence of muscular walls are the two noted features in the swim-bladder of *Polypterus*. The walls of the bladder are highly vasculars and are lined by two layers of striated muscle fibres. The bladder is supplied by a pair of pulmonary arteries arising from the last pair of epibranchial arteries and the corresponding veins enter into the hepatic vein below the sinus venosus. In the dipnoans the swim-bladder is called the lung and the inner walls are produced into numerous alveoli. The swim-bladder resembles the tetrapod lungs both structurally as well as functionally. In Neoceratodus it is single lobed, while in Protopterus and Lepidosiren it is bilobed (Fig. 5.64 H, I, J). Other details regarding the structural construction, blood and nerve supplies have already been dealt in the biology of the lungfishes. In Acipenser, the swim-bladder is short and oval in shape. The ductus pneumaticus enters the bladder ventrally and it opens into the gut posterior to the pharynx. The glottis is lacking and the opening into the oesophagus is closed by the simple constriction of the ductus pnematicus. The walls of the bladder are fibrous and thick but the inner walls are smooth. In Acipenser, both the left and right lobes develop from the dorsal side of the oesophagus in the embryonic stage, but the left one becomes completely obliterated and right one gives rise to the adult swim-bladder.

In *Amia* and *Lepisosteus* the swim-bladder is an unpaired sac extending nearly the entire length of the body cavity. In both the cases rudiment of the left lobe appears during development but persists only for a short time. The ductus pneumaticus opens into the oesophagus posterior to the pharynx through a dorsal slit-like glottis. The walls are highly vascular and exhibit sacculations resembling the pulmonary alveoli (Fig. 5.64D). The sacculations or the respiratory pouches are arranged in two lateral rows. As regards the development of sacculations the swim-bladder of Lepisosteus is more advanced than that of *Amia*. There are some more minor differences regarding the supply of blood. The swim-bladder in Amia gets arterial blood from the pulmonary arteries, while that of Lepisosteus gets arterial branches from the dorsal aorta. The blood from the bladder is returned by the left ductus Cuvieri in Amia and by the right postcardinal in Lepisosteus. *Gymnarchus* presents an intermediate stage where the efferent branchial arteries from the third and fourth gill-arches join to form a common root for the emergence of the pulmonary and coeliacomesenteric arteries (Fig. 5.64K). Amongst the dipnoans, the swim-bladder of Neoceratodus resembles that of Lepisosteus. The walls are sacculated and acts as the 'lung'.

In *Clupea harengus*, the ductus pneumaticus opens into the fundus of the stomach and there is a second duct from the posterior part of the swim-bladder opening to the exterior near the anus (Fig. 5.64E). Similar posterior opening is present in *Pellona*, *Caranx*, *Sardinella*. The swim-bladder varies extensively in size and shape. In some forms it gives off many branched diverticula. In many fishes, the anterior prolongations of the swim-bladder come into close contact with the wall of the space containing the internal ear. In *Clupea*, the narrow anterior end of the swim-bladder enters into a canal in the basioccipital of the skull and divides into two slender branches. The anterior end of each branch dilates to form a round swelling and lies in close contact with the internal ear. A more or less similar condition is observed in *Hilsa ilisha*.

In many fishes finger-like diverticula develop from the swim-bladder. In *Gadus*, a pair of diverticula originating from the anterior part of the bladder projects into the head region. In *Otolithus*, each antero-lateral end of the swim-bladder gives rise to an outgrowth which sends one anterior and a posterior horn. In *Corvina lobata*, many such branched diverticula develop from the lateral walls of the swim-bladder.

Usually in most cases, the swim-bladder is divided transversely into an anterior and a posterior chambers as seen in cyprinoids, *Essox*, *Catostomus*, *Pangassius*, *Corvina*, etc. But the longitudinal division of the swim-bladder is rare. In *Arius* the swim-bladder is splitted longitudinally. In *Notopterus*, a longitudinal septum divides the swim-bladder into two lateral chambers. Due to the presence of septum or septa, the internal cavity of the swim-bladder is either completely or partially divided.

Modifications of Physoclistous condition. The swim-bladder in all teleosts begins as a physostomous type but in the adult condition the ductus pneumaticus is degenerated to become a physoclistous type. A typical physoclistous swim-bladder consists of a closed sac having two compartments—an anterior and a posterior. These two compartments are intercommunicated through an aperture (*ductus communicans*). The opening and closure of this aperture is regulated by circular and radiating muscles which act as the sphincter. The anterior chamber is formed by the enlargement and forward growth of the budding swim-bladder, while the posterior chamber develops as an enlargement of the ductus pneumaticus. This typical structural plan is modified in certain forms. The posterior chamber with retia mirabilia becomes flattened almost to the point of obliteration and is designated 'oval' as seen in the families like Myctophidae, Percidae, Mugilidae. The oval is a thin-walled highly muscular area specialised for the reabsorption of gases (See Fig. 5.63D). The opening of the oval is guarded by circular and longitudinal muscles. This device is of great significance for the fishes undergoing rapid vertical movements.

Histological modifications. The morphological modifications of the swim-bladder is accompanied by the histological modifications in different fishes. In fishes, the swim-bladder acts as a hydrostatic organ. It helps the fishes to sink or ascend to various depths by altering the gas content in the bladder. In fishes having open ductus pneumaticus, the volume of gas content in the bladder can be changed by swallowing or removing at the surface. But in some physostomous and all physoclistous fishes this process of gas transference is done directly from the blood stream. Inside the bladder there is an oxygen producing device and an oxygen-absorbing device. The swim-bladder is a vascular structure but the degree of vascularisation varies in different teleosts. In some species of the families Clupeidae and Salmonidae the capillaries are uniformly present all over the swim-bladder, but in most cases these highly vascular interlacing and tightly packed capillaries form a mass called the rete mirabilis. The anterior chamber of swim-bladder shows the tendency to become differentiated into oxygen-producing area called the *red body*. The oxygen is produced by the reduction of the oxyhaemoglobin in the erythrocytes when brought into close contact with the secreting epithelial cells of the gas gland. The red body consists of an internal oxygen-secreting cells (*gas gland*) and supplied by the blood-vessels from the retia mirabilia (sing. rete mirabilis). It forms a complicated structure where the arterial and venous capillaries communicate only after reaching the gas gland. The most primitive condition is observed in Pickerel where the gland is covered by thick glandular epithelium which is thrown into a number of folds. In eels and some other fishes, the red bodies are non-glandular in nature but serve the same physiological function. The red gland is supplied with blood from the coeliac artery and is returned to the portal vein. The activity of the red gland is controlled by the vagus nerve. In the fishes with the functional ductus pneumaticus the gas glands are absent but in eels this function is taken up by this red gland. In the physoclistous fishes, the anterior region is modified for gas production and the posterior region or chamber is specialised for the absorption of gas into the blood. The posterior chamber becomes excessively thin walled to facilitate gas diffusion. Beneath the walls, the gas is absorbed directly into the blood. The formation of the oval in some fishes, is a special development for the absorption of gas. The wall of the oval is very thin and highly vascular. Through this epithelial lining oxygen can easily pass to the network of vessels. This gas absorbing region receives blood supply from the dorsal aorta and the blood is returned to the postcardinal vein. The activities are governed by the sympathetic nerves.

The histological differentiation for the gas production and gas absorption is a very significant achievement in fishes. The gas produced by the red body is mostly oxygen and this oxygen is readily absorbed or diffused from the swim-bladder directly into the capillaries. The oval is modified for gas absorption to many fishes. By the alternate process of gas production and gas absorption, the internal pressure and volume of the gas content inside the swim-bladder can be increased or decreased. The red body is usually confined to the anterior chamber, but in the fishes where the anterior chamber becomes secondarily associated with the auditory function, the gas gland may be confined to the posterior chamber.

Relation between swim-bladder and auditory apparatus

The swim-bladder, in many fishes, becomes intimately connected with the internal ear. This connection possibly enables the fishes to transmit change of pressure to the perilymph. This association exhibits a gradual trend of evolution from the simple to complex. In *Gadus*, *Megalops* and others, this connection is very simple. A finger-like diverticulum, after originating from the anterior end of the swim-bladder, joins the membrane covering an opening of the auditory capsule. In the Clupeidae, the situation is more advanced and a pair of such tubular outgrowths enters inside the auditory capsule. Each branch again divides into two, each terminates to a swollen vesicle. These vesicles are enclosed inside the prootic and pterotic bones. The vesicles touch a process coming from the membranous labyrinth. But in Carps and Siluroids (order Ostariophysi), this connection is more of advanced nature. The connection is effected by a chain of ossicles called the *Weberian ossicles* (named after the discoverer Weber in 1820). These ossicles are not homologous to the ear ossicles of other vertebrates, but are formed by the specialisation of the anterior vertebral segments.

WEBERIAN OSSICLES

The perilymphatic sac and the anterior end of the swim-bladder are connected by a series of four ossicles (Fig. 5.65) which are articulated as a conducting chain. Of the four, the *tripus*, *intercalarium* and *scaphium* actually form the chain, while the fourth one, *claustrum* lies dorsal to the scaphium and lies in the wall of posterior prolongation of the perilymphatic sac. The function of these ossicles is controversial. It is regarded that the Weberian ossicles either help to intensify sound vibrations and convey these waves to the internal ear or help to understand the state of tension of air pressure in the bladder and transit changes of such pressure to the perilymph to set up a reflex action. There are various views regarding the actual process of derivation of these ossicles. De Beer (1937) and Watson (1939) regarded that these are detached or modified processes of the first three anterior vertebrae.

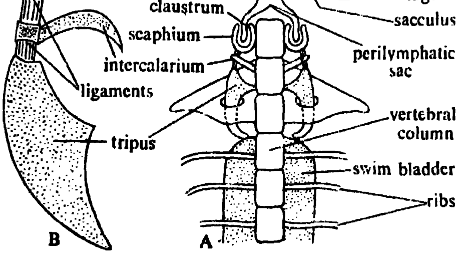


Fig. 5.65. (A) Weberian ossicles and their relation with other structures in *Catastomus*. B. Showing the different parts of Weberian ossicles.

FUNCTIONS OF SWIM-BLADDER

The swim-bladder in fishes performs a variety of functions.

Hydrostatic organ. It is primarily a hydrostatic organ and helps to keep the weight of the body equals to the volume of the water the fish displaces. It also serves to equilibrate the body in relation to the surrounding medium by increasing or decreasing the volume of gas content. In the physostomous fishes the expulsion of the gas from the swim-bladder is caused by way of the ductus pneumaticus, but in the physoclistous fishes the superfluous gas is removed by diffusion.

Adjustable float. The swim-bladder also acts as an adjustable float to enable the fishes to swim at any depth with least effort. When a fish likes to sink, the specific gravity of the body is increased. When it ascends the swim-bladder is distended and the specific gravity is diminished. By such adjustment, a fish can maintain an equilibrium at any level.

Maintain proper center of gravity. The swim-bladder helps to maintain proper center of gravity by shifting of the contained gas from one part of it to the other and thus facilitates in exhibiting a variety of movement.

Respiration. The respiratory function of the swim-bladder is quite significant. In many fishes living in water in which oxygen content is considerably low, the oxygen secreted in the bladder may serve as a source of oxygen. In a few fishes, specially in the dipnoans, the swim-bladder becomes modified into the 'lung'. The 'lung' is capable of breathing atmospheric air.

Resonator. The swim-bladder is regarded to act as a resonator. It intensifies the vibrations of the sound and transmits these to the ear by the Weberian ossicles.

Production of sound. The swim-bladder helps in the production of sound. Many fishes, *Doras*, *Platystoma*, *Malapterurus*, *Trigla* can produce grunting or hissing or drumming sound. The circulation of the contained air inside the swim-bladder causes the vibration of the incomplete septa. The sound is produced as the consequence of vibration of the incomplete septa present on the inner wall of the swim-bladder. The vibrations are caused by the movement of the contained air of the swim-bladder. Sound may also be produced by the compression of the extrinsic and intrinsic masculature of the swim-bladder. *Polypterus*, *Protopterus* and *Lepidosiren* can produce sound by compression and forceful expulsion of the contained gas in the swim-bladder. In *Cynoscion* male, the *musculus sonorificus* probably helps in compression.

Relationship between swim-bladder and lung

The swim-bladder in fishes and the lungs of tetrapods are closely similar in structure and development. Both of these structures are intimately associated with the gut. The lungs of higher vertebrates arise exactly the same way as that of the swim-bladder in fishes. Both develop as outgrowths from the gullet and the glottis occupies exactly the same position. But the exact nature of such similarity becomes difficult to estimate because of the lack of connecting fossil records. The evidences advanced by the study of embryology and comparative anatomy make the data more confusing. Figure 5.66 shows the relationship of swim-bladder of a few fishes and lungs in higher vertebrates with the gullet. The swim-bladder in fishes shows a gradual sequence of evolution from the simple to complex and there is general tendency to become lung-like in structure and function. In dipnoans and bichirs, the swim-bladder is actually a true air-breathing organ. In the primitive stage as shown by the sturgeon and many other fishes, the swim-bladder is a simple sac-like structure filled with a mixture of gases and subserves hydrostatic function. But in Amia, Lepisosteus and dipnoans the inner wall of the swim-bladder is richly vascularised and the surface area is increased by the development of pulmonary alveoli. In most cases, the swim-bladder is a single structure, but in Polypterus, Amia, Lepisosteus, Protopterus, Lepidosiren, the swim-bladder is paired (unequally developed in Polypterus). The right portion is long and the left one is of much shorter structure and opens by a single slit-like aperture (glottis) into the gullet. The arrangement of blood vessels to this particular organ, specially in the dipnoans, is very similar to that of the amphibians.

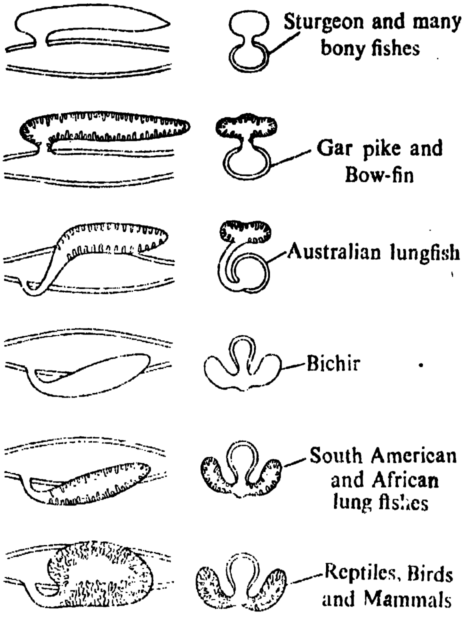

Sturgeon and many bony fishes
Gar pike and Bow-fin
Australian lungfish
Bichir
South American and African lung fishes
Reptiles, Birds and Mammals

Fig. 5.66. Showing the relationship between the swim-bladder and lung with the oesophagus in some fishes and tetrapods.

From the above facts, it is apparent that the swim-bladder and the lungs of the tetrapads are strikingly similar in origin, structure and function. Existence of such close parallelism led many workers to think that the swim-bladder of fishes is the forerunner of the tetrapod lung in the phylogenetic history of the vertebrates. But such an idea is not supported by the geological evidence. The presence of lung is geologically more primitive than the swim-bladder of the fishes. This occurrence rejects the plea of the derivation of the lung directly from the swim-bladder, but their monophyletic origin is a very popular notion. It is regarded that the placoderms constitute the most primitive gnathostomes and they possess swim-bladder. The lungs of tetrapods and the swim-bladder of the modern fishes have evolved from the placoderm source. This idea appears very simple to interprete, but the actual records of evolution are lacking. Diverse opinions exist on this particular issue. The most recent trend is to assume that the swim-bladder originated from a paired pouches which become fused to one in the course of evolution (Fig. 5.67). This condition is observed in fishes where the swim-bladder is simply hydrostatic in function. The swim-bladder of Polypterus, Protopterus and Lepidosiren presents fairly the primitive condition because in all of them the swim-bladder is paired and transformed into the 'lungs'. Now the question arises regarding the relationship between hydrostatic and respiratory types of the swim-bladder. The fishes having respiratory swim-bladder (Polypterus, Protopterus and Lepidosiren) can not be regarded as the progenitors of the teleosts possessing the swim-bladder of hydrostatic type. So it is logical to think that the fishes having hydrostatic type of swim-bladder evolved independently. Nothing more can be enlightened on this particular aspect, as our knowledge about the swim-bladder of the crossopterygians is insufficient. In the next chapter, while dealing with the origin of the Amphibia it has been shown that the amphibians evolved from the Crossopterygian ancestors. Under the circumstances, it is extremely difficult to draw any conclusion on the actual relationship between the swim-bladder in fishes and the lungs in the tetrapods. Although both the lungs and swim-bladder originated as paired outgrowths from the gullet, one cannot be definite that the same paired pouches are involved in all the cases. Further research on this line is required to give a clear idea.

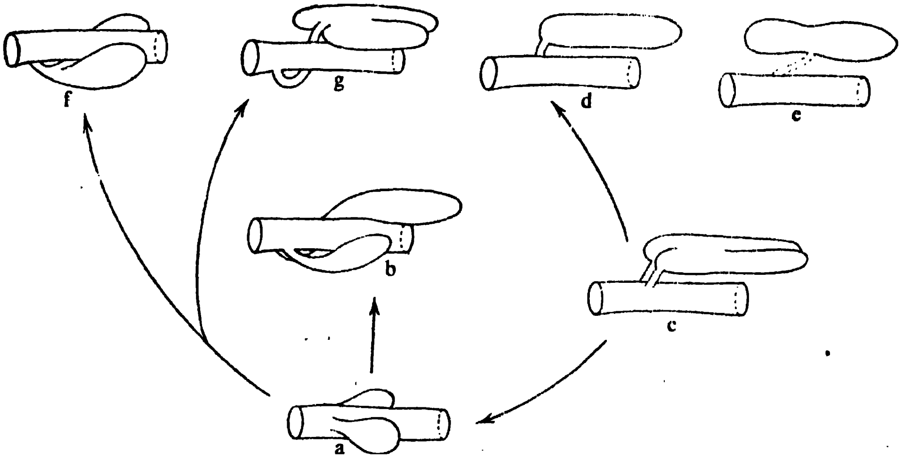


Fig. 5.67. Schematic representation of the phylogeny of the swim-bladder in fishes (after Jollie). (*a*) Hypothetical equal two lobed swim-bladder. (*b*) *Polypterus*. (*c*) Primitive actinopterygian. (*d*) Physostomous type. (*e*) Physoclistous type. (*f*) Amphibians. (*g*) Dipnoans.

CIRCULATORY SYSTEM

The structure of heart in fishes shows little variation. In Chondrichthyes, the heart consists of a sinous venosus, a ventricle, an auricle and a conus arteriosus. The conus arteriosus proceeds forward as a stout tube called the ventral aorta. The number and arrangement of valves in the conus arteriosus are the most notable features in the different fishes. In teleosts, the conus arteriosus is ill-developed and contains one or two sets of valves. In some teleosts the conus is altogether unrepresented. In teleost a large bulbus arteriosus is present at the base of the ventral aorta. The bulbus arteriosus is the dilated part of the base of the ventral aorta. It is not a part of the heart, but a part of the arterial system. In elasmobranchs and ganoid fishes the valves in the conus arteriosus are numerous and are usually arranged in three longitudinal rows. In many elasmobranchs there are six sets of valves. But reduction in the number of valves in the conus arteriosus is the common tendency in the evolution of fishes (Fig. 5.68). In dipnoans the auricle shows an advancement over other fishes, where it divides incompletely into left and right halves by an incomplete interauricular septum. This modification is due to acquisition of aerial respiration. In dipnoans, the swim-bladder is transformed into the 'lung' and the oxygenated blood from the 'lung' is carried into the left auricle.

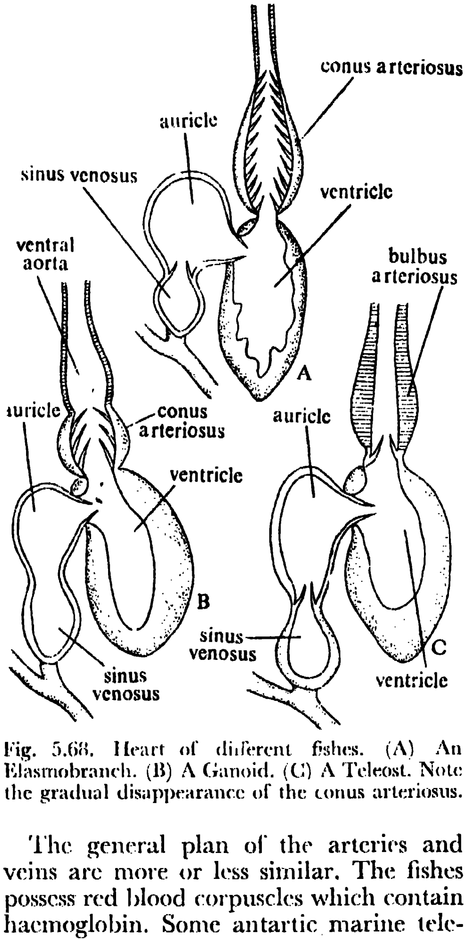


Fig. 5.68. Heart of different fishes. (A) An Elasmobranch. (B) A Ganoid. (C) A Teleost. Note the gradual disappearance of the conus arteriosus.

The general plan of the arteries and veins are more or less similar. The fishes possess red blood corpuscles which contain haemoglobin. Some antartic marine teleosts belonging to the family Chaenichthyidae have colourless blood, i.e., the haemoglobin is lacking. The leptocephalus larval stage of the Eel possesses colourless blood.

ORGANS OF OFFENCE OR DEFENCE IN FISHES

Fishes exhibit wide range of adaptive radiation. To meet special needs, the different members of the fishes have developed many adaptive devices which play a number of role in the economy of their life. Some of such devices upon which the fishes depend for protection against their enemies are described below. These are: (1) Protective covering of scales over the body. (2) Electric organs. (3) Poison glands and the associated spines. (4) Phosphorescent organs. (5) Colouration.

Scales

The body of all fishes (except the members of the family Siluridae and some bottom-dwellers) is covered by an exoskeleton in the form of scales. The mode of development of scales in fishes is different. In elasmobranchs, the scales originate from the dermal papillae with contribution from the epidermis, while in other fishes these are derived exclusively from the dermis. The size and shape of the scales differ greatly in different forms. In Eels the scales are minute and lie deeply embedded in the dermis. The scales are usually present throughout the body surface, but in some fishes, Chimaeras, Polydon and Acipenser the scales are present is some localised areas. The primitive fossil fishes possess exoskeleton in the form of plates and scales which consist of three distinct layers. The layers are: (1) Innermost layer of *isopedine*, (2) median *spongy vascular* layer and (3) outermost layer of *dentine*. Structurally five types of scales are recorded in fishes. These are:

Placoid scale. This type of scale is universally found in elasmobranch fishes with a few exceptions. The placoid scales appear first in the ancestral shark of the Upper Devonian time. In Chimaeras, these develop during embryonic life but soon disappear excepting in certain scattered regions. Each scale consists of a rounded or rhomboid bony plate which remains embedded in the dermis. A spine projects outward from the basal plate. The spine projects outward from the epidermis, and points posteriorly. The structure of placoid scales is already dealt in details in the biology of *Scoliodon.*

Ganoid or Rhomboid scales. This type of scale shows considerable diversities. Usually these are rhomboidal plate-like structures and remain closely fit together at their margins. The ganoid scales exist in two forms: (1) *paleoniscoid ganoid scale* present in *Polypterus* and (2) *lepisosteoid scale* present in gar-pike. In paleoniscoid ganoid scale, the deepest layer is composed of compact bone-like *isopedine,* the next is made up of hard *dentine* (*cosmine*) and the outer side is composed of hard translucent mesodermal material called *ganoin*. The usual spongy-bone layer next to isopedine is absent and the cosmine layer is reduced. In the second category of scales the spongy-bone and cosmine layers are totally eliminated and the ganoin lies upon the innermost isopedine layer.

Cosmoid scales. This type of scale is the characteristic feature of the primitive members of the crossopterygians and dipnoans. These have the same structural plan as that of the bony armours in ostracoderms and in many placoderms. This type of scale has four distinct layers, (*i*) innermost layer is called the *isopedine* layer which resembles compact bone; (*ii*) the next layer contains spongy bone with many vascular lacunae; (*iii*) the next layer is composed of cosmine resembling hard dentine and (*iv*) the outermost layer has an enamel-like consistency.

The cosmoid and ganoid type of scales are fundamentally similar and are usually described by many authors under one category. The ganoid type is regarded to have derived from the cosmoid forms in course of evolution.

Cycloid scales. This type of scale has rounded form. The centre of the scale is thicker and gradually thins out towards the margin. Each scale has concentric lines of growth. The scales are situated in the dermal pockets. This type of scale is present in teleost and in surviving dipnoans.

Ctenoid scale. This type of scale has rounded shape and the free margin possesses many comb-like projections. This type of scale is present in most teleosts. These are also embedded in small dermal pockets. The basal end of this type of scale is usually wavy.

The cycloid and the ctenoid scales are basically built on the same fundamental plan. The origin and development of these two types of scales are also similar. The cycloid scales are regarded to be phylogenetically more primitive, because cycloid scales are recorded in Cretaceous period. Transitional stages between the cycloid and ctenoid scales are found in many fishes which prove that ctenoid scales have evolved from cycloid forms. In some flounders, the upper side is provided with ctenoid scales and the underside is lined by cycloid scales. Such a combination of two types of scales is quite common in some other fishes also.

Modification of Scales

The scales in fishes have undergone modifications for specialised functions. The teeth in sharks are modified placoid scales and transitional stages in the process of transformation are encountered in these forms. The lateral rows of blade on the 'saw' of the saw fish are modified placoid scales. In *Tetrodon* (globe fish) and *Diodon* (Porcupine fish) the scales become transformed into protective spines. In *Acanthurus* (Sturgeon fish) the scales at the base of the tail have been transformed into sharp cutting blade.

In *Cetorhinus* (Basking shark) the gill-rakers are modified scales. In *Hippocampus* (Sea horse) and *Syngnathus* (Pipe-fish) the scales become fused to form protective bony rings round the body.

Scales and age of fish

The cycloid and ctenoid scales help in calculating the age of fishes. The scales grow as the fish grows. The fishes inhabiting specially the temperate zones leave distinctive record of age and growth rate on the scales. The scales appear first at a very young stage. During summer when the nutritional source is abundant, the fish grows very fast. Simultaneously with the rapid growth of the fish, the scales also grow. In winter the growth rate is slow and the difference is distinctly marked by concentric 'rings'. By counting the annual rings (or lines of growth) the age of a fish can be determined with a degree of accuracy.

Electric organs

Many fishes possess specialised organs by which an electric current is generated. This unique property of generating electric current is nowhere observed in animal kingdom. About two hundred fifty species of fishes, both elasmobranchs and teleosts, are recorded to possess *electric organs*. Presence of electric organ in different fishes is difficult to explain from the phylogenetic point of view but these organs have possibly evolved independently within the fishes to meet certain piscine needs. Many fishes possess electric organs and it is difficult to give a roll call of all the species. However, the following fishes are notable in having well defined electric organs. Amongst the elasmobranchs, the electric rays (*Torpedo* and *Narcine*) and the Skates (*Raja*) have well-developed electric organs. Members of a few families of the teleosts have developed the electric organs. They are: (1)

Electrophorus electricus inhabiting the rivers of South America. (2) *Gymnarchus* and *Mormyrus* found in the rivers of Africa. (3) *Malapterurus* is the typical African catfish. (4) Two star-gazers, the American *Astroscopus* and the Mediterranean *Uranoscopus* are some of the best known electric fishes.

Structure and origin of electric organs. The size, shape and location of the electric organs vary greatly in the different fishes. However, the electric organs are built on the same and identical structural plan. Typically an electric organ is composed of disc-like cells called the *electroplates* or *electroplaxes*. These are embedded in a jelly-like extracellular matrix and are bounded together by connective tissue to form compartment or elongated tube-like structure. The jelly gets blood supply and one end of the electroplate is connected with the nerve fibre.

Each electroplate is a multinucleate syncytial cell with a clear cytoplasm and exhibits characteristic surface convolutions. The nervous end of each electroplate is generally smooth while the other or the nonnervous end bears large papillae. The electroplate cells are formed from the striated muscle cells together with the jelly-like masses. The development of the electric organ is studied in Torpedo. In

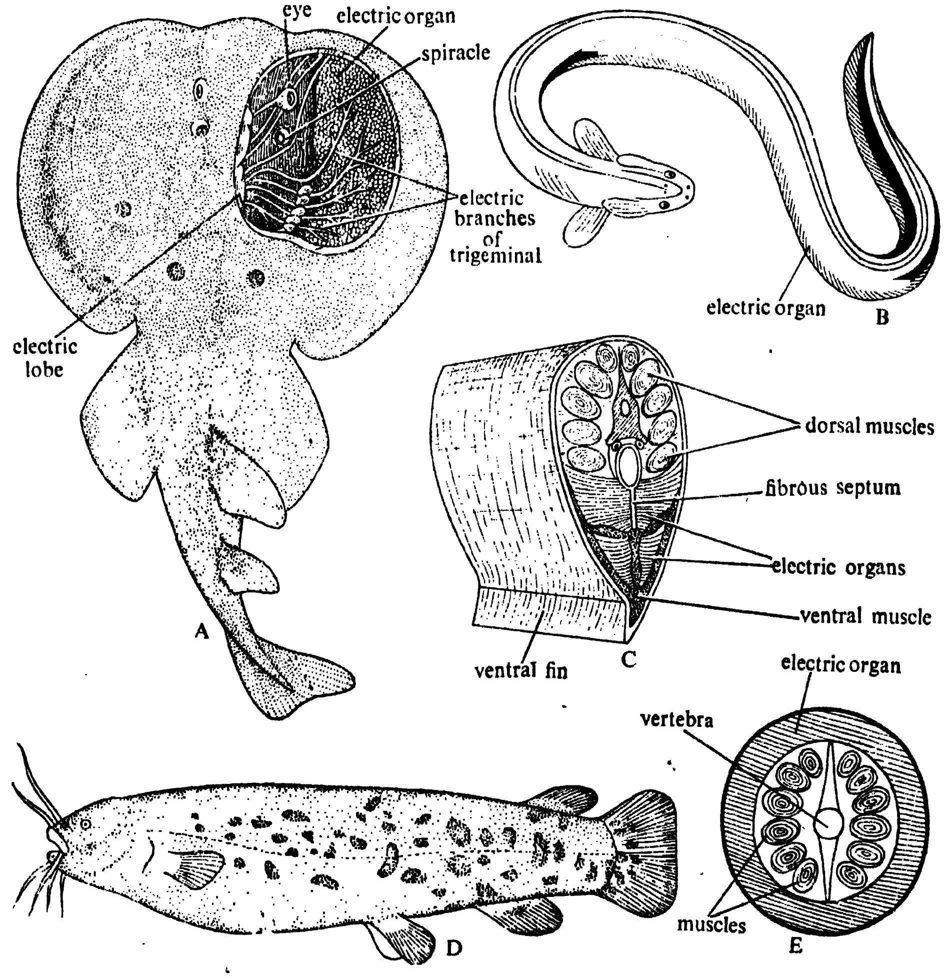

eye
electric organ
spiracle
electric branches of trigeminal
electric lobe
A
electric organ
B
dorsal muscles
fibrous septum
electric organs
ventral muscle
ventral fin
C
electric organ
vertebra
muscles
D
E

Fig. 5.69. Electric organs in different fishes. A. *Torpedo*. A portion of the right dorsolateral side of the head region is removed to show the electric organ and its innervation. (B) *Electrophorus electricus* showing the extent of the electric organ. (C) Transverse section of *Electrophorus electricus* to show the position of the electric organ. (D) *Malapterurus*. (E) Transverse section of *Malapterurus*. Note the peripheral position of electric organ.

this genus, the whole of the electric organ is developed from the branchial muscles which were originally meant for moving the gill-arches. In Electrophorus, Skates and Mormyrids the electric organs are modified muscles and are derived from the muscles of the tail. In Astroscopus, the electric organs are transformed eye muscles.

Electric organs in Torpedo. In *Torpedo* the electric organs are best developed amongst the elasmobranchs. The electric organs are paired and are situated on either side of the head between the anterior margin of the pectoral fin and the head (Fig. 5.69A). Each organ assumes a large flat kidney-shaped mass running through the entire thickness of the body. Each electric organ is composed of about 46 vertical columns which are separated from each others by fibrous tissues. Each column is composed of numerous electroplates. The electric organs are innervated by numerous nerve fibres deriving mainly from four nerves. These nerves originate from an *electric lobe* of the medulla oblongata and a nerve from the fifth cranial nerve. The innervated end of the electroplate is electrically negative and the other side is electrically positive. In this species, the electric current passes from the dorsal (positive) to the ventral side (negative). Torpedo generates electric current and the strength of the electric discharge generated by this fish varies from 30-50 volts. In other rays, the electric organs are comparatively smaller and situated at the lateral sides of the base of the tail. Narcine produces 37 volts, and a skate, *Raja clavata* generates about 14 volts of electric current.

Electric organs in Electrophorus electricus. The electric organs in electric 'eel' (*Electrophorus electricus*) are highly developed amongst the fishes and are capable of generating about 270-550 volts (Fig. 5.69B). On land Electrophorus can generate about 550 volts, but in water the voltages drop to about 270 volts partly due to short-circuit. Electrophorus (=*Gymnotus*) is a blind eel-like fish measuring about 2.5 metres long and inhabits the shallow muddy waters of the Amazon and many other South American rivers. The electric organs are paired structures situated one on each side of the body (Fig. 5.69C). These two organs are unequal in size and one is larger than the other. Each electric organ is composed of about 70 longitudinally arranged columns each containing a series of about 600 disc-like electroplates. The sum total of the tissue responsible for production of electric current comprises half of the total weight of the body. The electric organs are innervated by the nerves from the spinal cord. The polarity of the electric current is from the head to the tail end.

Electric organs in Malapterurus. In African cat-fish, *Malapterurus electricus*, the electric organs are located in the skin and thus form a thick covering over the body (Fig. 5.69 D, E). The electric organ in this particular fish is a dermal derivative and is divided into a number of compartments by connective tissue partitions. Each compartment is composed of numerous electroplates with their nervous ends directed towards the tail. The electric catfish is recorded to generate about 350-450 volts of electric current and the polarity is from the tail to the head end.

Electric organs in other teleosts. Uranoscopus and *Astroscopus* produce comparatively weak current by the electric organs. The electric organs are smaller in size and are innervated by the oculomotor nerves. These are modified muscle tissue and are restricted as two oval patches behind the eyes. In *Stealogenys elegans*, the electric organs exist in a groove below the dermis running from the anterior margin of the lower jaw to the basal end of the pectoral fins. *Mormyrus* produces weak electric shocks by the modified tail musculatures. *Mormyrus kannume* is capable of discharging a continuous stream of feeble electric current of variable frequencies. The discharge of electric current is lowest when the fish remains stationary, while during locomotion the rate is rapidly increased. The cerebellum and acoustico-lateralis regions of the brain become well-developed in *Mormyrus* for the co-ordination of the impulses.

FUNCTION OF THE ELECTRIC ORGANS

The electric organs are capable of generating electric current of variable voltages. The primary function of the electric organs is defensive, but secondarily subserve many other functions. The fishes with highly developed electric organs use these offensively in their hunt for food and defensively against their enemies. *Electrophorus*, *Torpedo* and *Narcine* are seen to paralyse fishes prior to feeding. The fishes with feeble electric organs utilise the electric field as the warning device. *Mormyrus* is seen to create an electric field around itself and if any object enters the field, the change is perceived by the fish. As *Mormyrus* possesses ill-developed eyes, the electric field works as a warning device. The highly developed cerebellum and the special cells at the base of the dorsal fin possibly help in the detection of the break in its electric field.

Poison glands in fishes

Many fishes have developed poison glands in association with the spines. Both these structures act as the organs of offence and defence. The poison glands are modified skin glands which have evolved for the protection from the enemies. Amongst the elasmobranchs, particularly in Sting rays, the serrated spines on the tail can inflict painful and fatal wounds. The spines are not connected with any special poison gland, but the secretory products of the mucous glands of the skin are possibly poisonous in nature. But amongst teleosts, well-formed multicellular poison glands have been developed in association with the spines. In *Synanceia*, the poison glands are highly developed. Each dorsal spine has a groove on both the sides and a poison gland is placed at the base of each groove (Fig. 5.70C). In *Trachinus*, the opercular spines are covered by thin skin except the tips. Each spine bears a groove and a poison gland opens at the base of the groove (Fig. 5.70 B, C). The poison gland secretes a toxic poisonous fluid which is forcibly introduced into the body of the victim with the spines. In many species, the opercular spines are perforated with a complete canal like that of a hypodermic needle. The basal end of each canal is connected with a poison gland and discharges its contents into the canal. In common cat-fishes (Siluridae) as exampliﬁed by *Heteropneustes fossilis*, each pectoral fin bears a spine with a poison gland at its base. In other members of the family Siluridae, there are deeply serrated dorsal and pectoral spines with their basal poison glands. In Scorpion fishes, the dorsal spines bear deep grooves and the duct from the basal poison gland is prolonged upto the tips to open there. In the star gazer (*Uranoscopus*) poisonous spines are present on the operculum as well as on the dorsal fin.

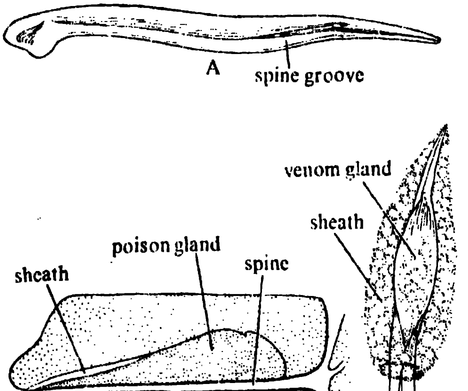


Fig. 5.70. Poison glands and spines of fishes. A. Spine of dorsal fin in *Trachinus*. B. An opercular spine and its poison gland of *Trachinus draco*. C. A dorsal spine and its poison gland in *Synanceia*.

Luminous (Luminescent or Phosphorescent) Organs

Many fishes, especially the deep sea forms, possess light producing organs called the *photophores* or luminous organs. Few elasmobranchs inhabiting the surface zone bear luminous organs. These organs are actually the modified integumentary glands and lie in the skin. Considerable variation in the number and disposition of the luminous organs is observed in different fishes. In majority of the cases the luminous organs are present along the ventrolateral sides of the head and body as one or two rows extending from the head to tail. But in *Opostomias* the photophores are arranged along transverse bands on the body. *Pachystomias* bears a pair of large complicated luminescent organs which is present under the eyes. In *Porichthyes*, numerous complex photophores are present along the lateral line of the body.

The photophores produce light by two ways in fishes. These organs house *photogenic symbiotic bacteria* in specialised areas, but most of the fishes are self-luminous, i.e., the light is emitted by *glandular cells* backed by pigmented reflector. The self-luminous photophores exhibit great structural evolution. In simple cases, these photophores are represented by radially arranged glandular tubules. These tubules get nerve supply from the peripheral nerves. In a complex photophore the dioptic parts are developed. In *Porichthyes*, the photophores after originating from the stratum germinativum of epidermis, become differentiated into two layers, the upper layer forms the *lens* while the lower layer constitutes the *glandular part.* The glandular part emits phosphorescent light and the other structures help to transmit the light. In *Pachystomias* each photophore assumes a cup-like form with its wall made up of many concentric layers. Numerous glandular cells are lodged in the cup and the cup is externally enveloped by pigmented layers. A lens-like body is present in the mouth of the cup and the overlying integument serves as an iris. The light reflecting layer is thick and highly developed. It is composed of reflecting spicules. These organs are innervated by a branch from the fifth cranial nerve.

In the photophores where light is produced by the symbiotic photogenic bacteria, such bacteria are present in the glandular tubules. This category of photophores is capable of producing light for a considerable period of time. The provision for off and on of the light production in the photophores is developed in many forms. In *Photoblepharon,* the light can be cut off by drawing up a fold of darkly pigmented fold like an eye-lid. In *Anomalops* the light is shut off by drawing the photophore downwards.

The controlling mechanism of production of light by the photophores in fishes is not fully known. The production of light is stimulated by injecting adrenalin and also by exposing to the electric shock. The activities of the photogenic bacteria are directly under the nervous control. In the self-luminous photophores the production of light is under the ultimate control of sympathetic nerves. So the role played both by the nervous and endocrine systems governing the physiological activities of the luminous organs is quite suggestive.

The significance of light production in fishes is quite diverse. The functions are: (1) In deep sea forms, the light produced by luminous organs helps to search the prey in dark environment. (2) Most deep sea angler-fishes use the light to lure the prey near the mouth. (3) In *Stomias* and related forms, the photophores are sensory in function and help to detect whereabouts of wandering prey. (4) The orientational pattern of photophores on the body helps to recognise individuals of the same species. (5) The luminous organs also serve as the defensive organs because of quick flashing of light which may frighten the enemies. (6) The sexual role of the photophores is also recognised in some instances by acting as the luminiscent lures.

Colouration

Fishes exhibit wide range of colour patterns which enable them to conceal themselves from their predators. The general colouration with characteristic markings, in the forms of stripes, bars or spots are usually constant in the individuals of a particular species. The colour in fishes is produced by the cells present in the skin. These are: (1) *Pigment cells* or *chromatophores* and (2) *Reflecting cells* or *iridocytes.* The chromatophores are large and branched cells containing pigment in the cytoplasm. Each chromatophore has a much branched sac-like cell body with thin wall. The contained pigment granules may be concentrated into a minute dot by contraction. Expansion of the pigment granules may result dispersion to form irregular colour pattern. The pigment granules deposited in each of the chromatophore may be either black, red, orange or yellow in colour. Other intermediate shades are produced by the blending effect of two or more of the primary colours. The iridocytes are made up of opaque crystals of *guanin.* The iridocytes are able to reflect light and are present either outside or inside the scales. The iridocytes, located outside the scales, give an iridescent silvery appearance while those situated inside the scales produce a reflecting layer (*argenteum*). A combination of the chromatophores and iridocytes produces interference effects so that a wide range of colour is produced in fishes. The relative abundance of the chromatophores with their particular kind of pigment granules as well as the iridescence and the reflecting capacity of the iridocytes play their role in determining the colour of a particular fish.

The significance of colour in fishes is three-folds: (1) Concealing colouration (cryptic), (2) Warning colouration (sematic) and (3) Sex colouration (epigamic). The cryptic colouration is achieved by two ways: (*a*) by assimilation with the background and (*b*) by breaking up the outline of the fish. Lack of pigmentation in the pelagic fishes is a typical example of assimilation. Many fishes living among weeds (e.g., *Hippocampus*, *Synognathus*, *Lophius* and many others) resemble the sea weeds in colour. Extreme cases are observed in *Phycodurus* and *Histrio histrio* (frog-fish) which, besides their matching colouration with the weeds, develop 'leaf-like' processes. Many reef-dwelling fishes show an extraordinary variety of colour markings. The significance of such markings is to break up the outline of the fishes. Many bottom living fishes have a darker upper side and the under side is lighter. In surface feeders, like *Hilsa*, *Catla*, the dorsal side is blackish and the colour becomes gradually lighter towards the lateral sides. In the shore-dwelling fishes inhabiting the sea bottom, the colour markings of the body imitate the background. *Orectolobus* (Carpet shark) imitates a weed-covered rocky background on which they live. The colour pattern is usually constant in a particular group of fishes, but the different species of the genus, *Ostracion* (Trunk fish) show a variety of colour depending on the environment they live. Such variation in colour is also observed among the individuals of the same species of Brown Trout (*Salmo trutta*).

Warning or Sematic colouration involves the adoption of special colour pattern which acts as the danger signals to the predaceous fishes. The fishes of this category have either poisonous flesh or possess venomous glands in association with the spines and the like. *Trichinus* (Weever-fish) provides an excellent example of warning colouration. The pectoral fin of *Solea* mimics the aggressively coloured dorsal fin of Weever and thus escape the eyes of the predators, because the predators think it to be the member of Weever-fish. *Torpedo ocellata* has conspicuous coloured spots.

Two sexes of many fishes show colour difference specially during the breeding season. Such a phenomenon becomes conspicuous in fishes which exhibit some sort of courtship. Colour difference appears during the breeding season and after the season is over the colours vanish, and two sexes become more or less similar. Usually the male individuals exhibit colouration which depends on genetic factors lodged in the Y-chromosome. In *Lebistes*, there are many 'races' of distinctive coloured males while the females are typically coloured. The significance of such colour change is not fully understood. Evidences have shown that such changes are associated with the sexual activities.

The characteristic colour pattern of a fish depends on the relationship between the chromatophores and the iridocytes. Majority of the fishes have the ability of either slow or instantaneous change of colour. Such a change is primarily due to the action of the chromatophores by (*i*) contracting or expanding the contained pigment granules, (*ii*) an increase or decrease in the number of chromatophores and (*iii*) altering the distributional pattern of the chromatophores in the skin. The physiological mechanism of the movement of the pigment granules within the chromatophores is not known. It is apparent that the initial stimulus of change of colour is received through the eyes and the direct action of light on the production of pigment is certain. Because absence of light (as examplified by the cave-dwelling fishes) leads to the disappearance of pigmentation. It is, however, suggested that both nervous and endocrine systems control the process. Slow changes of colour are under the control of hormones, while fast or instantaneous changes are under nervous control. The ability to change of colour is to convert the fishes to the same hue of the surroundings they inhabit and helps the fishes to survive in hostile environment.

NERVOUS SYSTEM

The organisation of nervous system is basically similar in different fishes. The *brain* and the *spinal cord* are covered by a single protective covering called the *meninx primitiva*. The spinal cord bears the *dorsal fissure* in most fishes, but the ventral fissure is lacking. The forebrain exhibits extensive variation. In most elasmobranchs, the cerebral hemispheres are widely separated, but in others the separation is not so well-marked. In the latter forms, at least a median depression is present which indicates the division of the anterior part of the forebrain. In most teleosts, the prosencephalon is not divided into hemispheres and the roof is nonnervous and thin. The floor of cerebral hemispheres (corpus striatum) is well-developed. In dipnoans the cerebral hemispheres are quite distinct anteriorly. The olfactory lobes are usually well-formed and are, in most cases, borne on long olfactory peduncles. In the rays and Acipenser, the olfactory lobes are solid structures. In general, the progression of telencephalon is limited not beyond the development of the olfactory centre. The diencephalon is moderately developed in fishes. Presence of *saccus vasculosus* and *inferior lobes*, especially in elasmobranchs, are the modifications of the lower part of the diencephalon. The saccus vasculosus has folded pigmented walls which acts as a pressure receptor. It is well-developed in deep-sea fishes. The optic nerves in elasmobranchs form chiasma, but in teleosts the chiasma is absent where the optic nerves simply cross or decussate. The cerebellum is poorly developed in sluggish fishes, but in active forms the cerebellum is prominent. Amongst the elasmobranchs, cerebellum is elongated in sharks, but is comparatively shorter in rays.

The medulla oblongata exhibits structural modifications in response to different functional responses. In certain fishes, two well-developed *vagal lobes* are present in the medulla oblongata. These lobes are highly developed in many teleosts and are very prominent in buffalo fish (*Carpiodes tumidus*). The *electric lobes* in Electric rays are the spherical projections of the floor of the fourth ventricle and innervate the electric organs. The origin and distribution of the cranial nerves are more or less similar in all the fishes.

SENSE ORGANS

Fishes possess specialised sense organs. The major sense organs are described below:

Eye. The eyes of fishes are the photoreceptors to see things under water. The eyes are typically built on the principle of a photographic camera. The eye ball is composed of three layers—the outer is the *sclera*, the median is the *choroid* layer and the innermost photosensitive layer is called the *retina*. The *lens* is mostly globular and the *cornea* is flat.

In elasmobranchs, the eyes are very large and in the deep-sea holocephalans the eyes are the largest. The eyes in most elasmobranchs, are held in position inside the orbit by a cartilaginous stalk or *optic pedicel*. In some sharks and rays the pedicel is slender, elastic and helps in the protrusion of the eyeball. Most conspicuous feature in the eye of elasmobranchs is the presence of cartilage in the sclera, absence of intrinsic muscles in the *ciliary body*, presence of a fold of *conjunctiva* recalling the nictitating membrane of higher forms (in a few sharks) and the presence of large rounded lens. In most elasmobranchs, a light reflecting layer called the *tapetum lucidum* (composed of guanin) is exceptionally well-developed. The tapetum lies in the choroid. In Basking shark, *Cetorhinus* and in an abyssal shark, *Laemargus*, the tapetum is wanting. In most teleosts, a silvery layer, *argenteum* is present between the sclerotic and the choroid layers. The cells composing the layer contain fine crystals. Absence of choroid process is a notable feature in the eyes of teleosts. A *choroid gland* is present which is not glandular in nature but composed of a complicated network of vessels (*rete mirabiles*). The retinal layer lacks the cones in elasmobranchs except *Mustelus*, *Myliobatis* and few other forms. In these forms the cones have been derived independently from the rods. In other fishes the eyes exhibit great variations. The cartilage in the sclera may be replaced by bony plates. The cones are present in teleosts. Accommodation of the eyes is caused by change of position of lens. This is accomplished by the *falciform process* in conjunction with *companula Halleri* in teleosts. The falciform process ends in a muscular knob called the campanula Halleri or *retractor lentis*. But in elasmobranchs, accommodation is brought about by the activities of the smooth muscle fibres. These fibres bring the lens towards the cornea. Deep sea teleosts inhabiting the total darkness possess enormous eyes. In these forms, pupil and the lens are exceptionally large. The rods are well-developed but the cones are totally lacking. The eye-ball is tubular in some deep-sea forms. Amongst the elasmobranchs, in a deep-sea electric ray, *Benthobates moresbyi*, the eyes are degenerated. Amongst the deep-sea teleosts, a few are blind and in others the eyes are degenerated. In *Ipnops murrayi*, the eyes have altogether disappeared. Certain cave-dwelling fishes have minute functionless eyes. In some teleosts, the eyes are adapted for vision in water as well as in air. The typical examples are *Periophthalmus* and *Boleophthalmus*. The eyes in these two forms are prominent and each eye can be rotated in all directions. In four-eye fish, *Anableps* of Central America, each eye has two pupils in adult. The eye is divided into two parts by a horizontal band. The upper half usually remains out of water and is used in aerial vision. In another fish, *Dialommus* two pupils are present in each eye which are actually circular transparent areas in an opaque and pigmented cornea.

The fishes possess monocular vision, i.e., the two eyes cannot be focussed on the same object. But certain deep-sea fishes have telescopic vision. The eyes are mostly present on the lateral sides of the head, but in flat fishes both the eyes are placed on the dorsal side.

Ear. The ear in fishes is represented only by the internal ear or *membranous labyrinth.* The internal ear is completely enclosed in the *otic bones*. The membranous labyrinth shows many structural peculiarities in elasmobranchs. As stated earlier, the internal ear is composed of three *semicircular canals* and three other parts (the *utriculus*, *sacculus* and *lagena*). The last three chambers contain *otoliths* (ear stones), namely the *lapillus*, *sagitta* and *asteriscus*. In many elasmobranchs, a small tube arising from the dorsal side of the *sacculus* opens to the surface of the head. This duct is termed the *invagination canal* which is homologous to the *endolymphatic duct* of other forms. In these forms the cavity of the membranous labyrinth is filled with sea water, rather than endolymph. In other fishes, a new endolymphatic duct appears and the invagination canal disappears altogether. As stated earlier, in some teleosts, the presence of *Weberian ossicles* correlates the function of swim-bladder with the equilibrating and auditory functions of the internal ear. In elasmobranchs, the experimental evidences have established that the ear may function as a vibration receptor.

Olfactory sense organs. In fishes the olfactory organs are paired and show an evolutionary advancement. In many fishes these organs may be just blind pits with olfactory epithelium or *Scheiderian membrane.* The olfactory epithelium may produce numerous Scheiderian folds to increase the area in fishes. In bony fishes, the nostrils are generally located on the dorsal side of the head, but in elasmobranchs these are situated on the ventral side. Excepting the Choanichthyes, the nasal cavities are not in communication with the mouth in other fishes, although an *oronasal groove* in some elasmobranchs foreshadows the condition in Choanichthyes.

Lateral line sense organs. Although the function of the lateral line sense organs in fishes is not ascertained with accuracy, these are present in all the fishes. These are regarded as the rheoreceptors. The sensory units of the organs are the *neuromasts* which in certain fishes are localised on the surface. The neuromasts are highly developed in elasmobranchs. In many fishes the neuromasts are located in the integumentary grooves which may form canals. The grooves may remain open in holocephalans, but in most bony fishes a closed *lateral line canal* is formed which communicates to the exterior by small pores perforating the scales. In *Miripinna*, the lateral line sense organs are placed on the elevations. Presence of ampullae and ampullary canals are peculiar to the elasmobranchs, although such ampullae are seen to be present in catfish, *Plotosus*. The *ampullae of Lorenzini* are the thermoreceptors found in elasmobranchs. The structure of these sense organs is described in the biology of Scoliodon. The *vesicles of Savi* (closely related to the ampullae of Lorenzini) occur on the ventral side of the body of *Torpedo*. These are closed sacs of unknown function. The *rostral sac* or *internasal organ* in *Latimeria* is not related to the ampullae of Lorinzini. The function of this organ is not known but it may possibly act as a theromoreceptor.

EXCRETORY SYSTEM

Adult fishes possess opisthonephros type of kidney. Although built on the same fundamental plan, the kidneys in fishes show great variation in shape. In most fishes, kidneys are extremely elongated structures and extend the entire length of the body cavity. They may attain voluminous size and the two kidneys show various degrees of fusion along the length. Usually the posterior sides of the kidneys are fused and the anterior ends remain free. The anterior part of kidney in almost all forms is nonrenal.

In elasmobranchs, the kidneys in two sexes differ structurally. In male the anterior nonrenal part of the kidney is well-formed and subserves reproductive function, but in female the anterior part of the kidney is functionless and degenerated. In teleosts, the anterior portion of the kidney is converted into lyinphatic tissue and does not perform any renal function. In teleosts there is no connection between testis and the kidney. Marine teleosts possess fewer number of glomeruli than the fresh water forms. In some cases, the kidneys are wholly aglomerular. In toadfish, *Opsanus tau* the kidneys are aglomerular.

REPRODUCTIVE SYSTEM

The sexes are separate and the sexual dimorphism is usually absent excepting some fishes. The male sharks possess claspers, the brood pouch in *Hippocampus* and pipe-fishes (Syngnathidae) are some of the striking features.

Male reproductive system. The *testes* are paired structures and are symmetrically placed in the anterior part of the coelom. The testes are attached with the body wall by *mesorchia.* The testes are roughly oval or elongated in shape. The testes often exhibit lobulated texture. In dipnoans, testes are enveloped by lymphoid tissue. The manner of transportation of the spermatozoa from the testis differs in many fishes. In most elasmobranchs, small *efferent ductules* arising from testis are connected with the *kidney tubules* of the anterior portion. In elasmobranchs, the connection of the efferent ductules from the testis and the *archinephric duct* occurs in the anterior region of the opisthonephros. This condition may be quite different in other fishes. In *Polypterus*, the kidney tubules at the posterior part of the kidney usually degenerate and subserve reproductive function. In *Protopterus* and many teleosts, separation of testis duct from archinephric duct represents the specialised condition.

In elasmobranchs, holocephalans and few teleosts internal fertilization occurs and is effected by *copulatory organ.* Clasping organs in elasmobranchs serve the purpose. In holocephalans, clasping organs of similar nature are present. In some teleosts the anal fin in males prolongs posteriorly into an intromittent organ called the *gonopodium.* The gonopodium is present in the 'guppy', a common aquarium fish. The intromittent organs found in teleosts are actually the specialisation of haemal spines of some caudal vertebrae.

Female reproductive system. In fishes the *ovaries* are paired structures. In some fishes unpaired ovary is present, which is actually formed by the fusion of two ovaries. The ovaries are attached to the body wall by the mesenteries. The ovaries are asymmetrically placed in some forms. In many elasmobranchs, the right ovary becomes greatly developed and the left one atrophies. In majority of the teleosts saccular ovaries are present and become greatly enlarged during breeding season. Other teleosts may possess solid ovaries. The structures concerned for the transportation of eggs from coelom to the exterior vary greatly in fishes. The members of the family Salmonidae and some other fishes the eggs escape through the *abdominal pores.* In addition to the abdominal pores, ducts for transportation of eggs exist in most forms. In elasmobranchs, *shell gland* is present in each *oviduct.* The shell gland is better developed in oviparous forms than the ovoviviparous species. In ovoviviparous dogfish, *Squalus acanthias*, temporary shell surrounds several eggs in the uterus and the eggs undergo early development within it.

The teleosts have saccular ovaries and possess short oviducts. The two oviducts may often unite posteriorly to form a single duct which opens by *genital pore.* Most of the teleosts are oviparous, but ovoviviparous forms are also common. The homology of the oviducts in different forms is not certain.

All the elasmobranchs are oviparous excepting *Rhinobatus* and *Trygonorhina* which are viviparous. Vaviparity accompanied by formation of *placenta* is also present in teleosts. Viviparity is quite widespread in the families of the order *Microcyprini.* Amongst elasmobranchs, viviparity accompanied by true placenta formation is quite common. In some sharks, the vascular chorion unites with the uterine wall. For the purpose of drawing nourishment from the maternal tissue, development of villi is also observed in *Torpedo* and *Trygon.*

MIGRATION OF FISHES

The fishes are notable for migration for the purpose of spawning. The inherent purpose of migration is not known. There are two opposing trends of migration in fishes: (1) *Catadromous migration*, i.e., the journey from river to the seas and (2) *Anadromous migration* meaning the reverse movement of the fishes from the sea to the river system. The life-history of the European eel (*Anguilla*) will give a clear idea regarding the migration of fishes. The life-history of this eel is categorised into four phases: (1) An ordinary yellow-eel representing the growing and feeding form in river, (2) changes into the silvery eel ready for seaward migration for spawning (breeding phase), (3) a pelagic larval phase and (4) the metamorphosis of the pelagic larval phase to *elver.* Anguilla undertakes long journeys for spawning. There are two distinct kinds of eel. The yellow coloured variety living in fresh water represents the feeding and growing forms. With the advent of autumn, majority of the yellow-eels become silvery and prepare to undertake migration to the spawning ground. During this transformation, the yellow. eels stop feeding, the eyes become greatly enlarged, the snout becomes sharper with thinner lips and the yellow colouration is replaced by a metallic silvery colour. The silver-eels are recognised by having matured reproductive organs and shrunken digestive tract. These silver-eels migrate down the rivers to reach the seas. It is recorded that the eels cover about 3000–4000 miles westwards from Europe or eastwards from America to their spawning ground in the Sargasso Sea off Bermuda. After the completion of spawning the parents die.

The fertilized eggs float for sometime and the youngs hatch out as the pelagic larvae. The larvae are called the *Leptocephali* having a flat leaf-like body. These tiny creatures are provided with elongated needle-like teeth for feeding. They now begin their long homeward journey and undergo metamorphosis and turn into the elvers (glass eels). The needle-like teeth are lost and the flattened body becomes cylindrical. The elvers, when attain about three years, start ascending the rivers in shoals to reach a suitable resting place. Here the elvers will feed and grow for some years to become the yellow-eels. The yellow-eels, on maturity, change into the silver-eels and start the same circle of migration.

Many marine fishes migrate to the river from the sea for spawning. This anadromous migration is observed in *Acipenser*, *Alosa*, *Salmo*, *Hilsa*. These fishes usually produce huge number of eggs to compensate the risk to which the eggs are subjected. Atlantic Salmon (*Salmo salar*) spawns during November and December. During this period they ascend to the rivers and give up feeding, as a consequence they lose weight. The silvery colour of the body is gradually replaced by a dull reddish-brown tint and the skin on the back becomes thick. Sexual dimorphism becomes evident. The males are characterised by having enlarged front teeth. The snout and the lower jaw become drawn out to form a prominent hook. The Salmons, after the selection of suitable spawning grounds, seggregate into pairs and produce shallow saucer-like nests where spawning takes place. The fertilized eggs sink and the females loosely cover the eggs by fine gravels. After the process, the fishes make return journey to the sea. A few of the male fishes survive to breed for the second time, but the females are able to reach the sea. They begin to take food and regain the silver colour. The Salmons do not spawn more than three times in their life span of eight to nine years. The North American Salmon of the Pacific coast (*Oncorhynchus*) exhibits similar spawning behaviour.

RELATIONSHIP BETWEEN THE CLASSES OF FISHES

Fishes are conveniently categorised into three broad classes—the Placodermi, Chondrichthyes (or Elasmobranchii) and Osteichthyes. Each of the class is characterised by having a number of individual specialisations. But the interrelationship between the three classes of the fishes becomes extremely difficult to interprete. The most important obstruction stands on this particular aspect is the absence of good fossil link. The placoderms were the earliest known gnathostomes and were the progenitors of the modern fishes, both the bony and cartilaginous forms. The placoderms represent a polymorphic group and exhibit wide range of adaptive radiation. Of the placoderms, the acanthodians were the most primatively constructed forms and possibly hold the ancestry of the other fishes. But the existence of the operculum in acanthodians becomes sometimes difficult to interprete, specially in the consideration of the phylogeny of the elasmobranchs. The old idea that the elasmobranch fishes with cartilaginous skeleton represented the most primitive forms does not hold true, because the recent workers on this line are unanimous on the primitiveness of the placoderms. This is attested by the paleontological records.

The osteichthyian fragments were abundant in mid-Devonian deposits. From the existence of the fossil records, the emergence of these forms prior to mid-Devonian strata is obvious, possibly in the early Devonian, if not, late Silurian times. Whether the two subclasses of the class Osteichthyes, viz., the Crossopterygii and the Actinopterygii have immediate common ancestry is not certain. It is most likely that the Actinopterygians and the Crossopterygians have common ancestor in the upper Silurian or early Devonian period. After originating from the common progenitors these two groups underwent wide diversification. The Crossopterygians, despite their abundance in the early part of the evolutionary history, exist to-day with a few living representatives. Whereas the actinopterygians have reached the pinnacle of evolutionary success and survive to-day by a countless number of forms.

The emergence of the elasmobranchs is still a debated issue. The absence of bony elements led many earlier workers to hold the view that the bony fishes have evolved from the elasmobranchs. But such a concept is rejected on the plea that the bone is actually a primitive material in the geological history. The earliest known fragmentary remains of the elasmobranchs (although rejected by many recent Ichthyologists) were discovered in the mid-Devonian deposits. But the records of the fossils of the bony fishes dated back to the early Devonian and late Silurian period. So the idea of the elasmobranch progenitor of the bony fishes is unacceptable. The elasmobranchs represent a well-defined group and their evolution from the shark-like polymorphic placoderms is supported by remote and incomplete evidence. The elasmobranchs have cartilaginous skeleton with no trace of true bony elements. So how can this group be evolved from the placoderms where the skeleton is bony is difficult to explain. Many recent authors incline to think that the elasmobranchs have evolved from the bony ancestor (the placoderms) through neoteny. Evolutionary plasticity of the youthful stages and their subsequent role in evolutionary dynamics have been greatly emphasised by Garstang and Willey. It is likely that the bony ancestral forms during their larval phase become sexually mature and reproduce in that condition. Such a neotenous form possibly holds the key of the emergence of the elasmobranchs. There are evidences in favour of this idea. The evidences are: (1) The cartilage is an embryonic tissue. So the presence of exclusively cartilaginous skeleton indicates the embryonic condition. (2) The neotenous condition is observed in a few living teleosts as examplified by *Clariallabes*. An amphibian larval form *Axolotl* (discussed in the next chapter) exhibits the same phenomenon. So the cumulative evidences force us to believe the emergence of the elasmobranchs from the bony fishes through the phenomenon of neotony.

SUMMARY

(1) The fishes are the primary aquatic vertebrates which exploit the every nook and niche of the domain of water. They have undergone extensive adaptive modifications for living in the watery home.

(2) The fishes are notable for their countless number and wide diversities of form, habit and habitat.

(3) Despite their diversities, all the fishes are built on the fundamental piscine plan. All of them are characterised by possessing many common diagnostic features.

(4) The classification of the fishes is a controversial issue. This is because of our incomplete knowledge of their fossil forms. The older idea of the inclusion of all the fishes under one superclass Pisces is no longer considered.

(5) All the fishes (extinct as well as extant) are conveniently classified into three classes of equal taxonomical status. The classes are: *Placodermi* (including exclusively the fossil fishes), *Chondrichthyes* (all the cartilaginous fishes) and *Osteichthyes* (embracing the bony fishes). But the scheme of division of the three classes into smaller units differs considerably.

(6) The placoderms constitute the most primitive fishes which were the progenitors of the modern fishes.

(7) The bony fishes represent the highest developed forms. This group also includes the crossopterygians, from which the amphibians have evolved in time and space.

(8) The anatomical organisation of fishes becomes modified according to the different modes of living.

(9) All the fishes, except the members of the family Siluridae and bottom dwellers, possess dermal scales covering the body. There are various types of scales, viz., placoid, cosmoid, ganoid, cycloid and ctenoid. The scales form a sort of protective device and may be modified into variety of structures in different fishes.

(10) The teeth and the digestive system become specialised in accordance to their specific feeding habits.

(11) All the fishes respire by the gills. Some teleosts are able to respire on land by the accessory aerial respiratory organs.

(12) The swimbladder, specially in bony fishes, has undergone extensive specialisation. It is primarily a hydrostatic organ which may subserve many other functions in certain fishes. The transformation of the swimbladder into the 'lung' particularly in the dipnoans is significant.

(13) Many fishes possess well-developed protective mechanisms. The ability to generate electric current by the electric organs, the possession of venom and poisonous spines, the phosphorescent organs and the colouration in some forms of fishes are special achievements on which the fishes depend for protection against their enemies.

CHAPTER 6

Phylum Chordata—AMPHIBIANS

The transition from water to land is a very remarkable step in the phylogenetic history of the vertebrates. This conquest of land was first initiated by the primitive amphibians in the Devonian period (Fig. 6.1) and was completed by the reptiles in course of time. Although the amphibians are credited as the first land-dwellers, they are not fully adapted to the terrestrial environment. They constitute a sort of transitional group, neither fully aquatic nor fully terrestrial, but have made a compromise between the two opposing environments. However, on coming to the land, the amphibians had to confront diverse problems of land life, as a result radical changes have occurred in their biological organisation. This chapter deals with the biology of the amphibians.

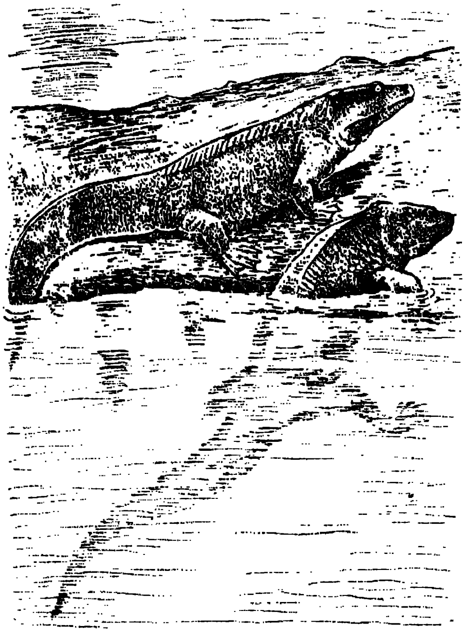


Fig. 6.1 *Icthyostega* was the pioneer amongst the vertebrates to leave the primal aquatic abode and came to the land during the late Devonian-period. Being amphibian in structure and function, *Icthyostega* retained many features of its piscine ancestor.

IMPORTANT FEATURES

The amphibians represent the primitive group of land vertebrates. Although the members of this class exhibit great structural diversities, they possess many common diagnostic features. The features are: (1) The body is bilaterally symmetrical. (2) They are cold-blooded vertebrates. (3) The skin is naked and highly glandular. Most of the living forms are scaleless except the members of the order Gymnophiona where internal scales are present. (4) Two pairs of limbs are usually present. The forelimbs are provided with four digits and the hindlimbs are usually with five digits. The digits are clawless. (5) Distinct neck is absent. (6) The heart is composed of two auricles, one undivided ventricle, one sinus venosus and one conus arteriosus. There is no provision for separation of oxygenated and deoxygenated blood in the heart. (7) The tympanum is present and is connected with the inner ear through a rod-like columella. (8) They are oviparous and the eggs are large, yolky and telolecithal. (9) The amnion and allantois are absent. (10) An aquatic larval stage (Tadpole larva) is usually present.

OUTLINE CLASSIFICATION

The class Amphibia is divided into the following orders:

EXTINCT ORDERS

1. *Labyrinthodontia*—e.g., *Eryops.*
2. *Phyllospondyli*—e.g., *Branchiosaurs.*
3. *Lepospondyli*—e.g., *Diplocaulus, Lysorophus.*

LIVING ORDERS

1. *Gymnophiona* (or *Apoda*)—e.g., *Ichthyophis.*

2. *Urodela* (or *Caudata*)—e.g., *Necturus, Triton.*

The order Urodela includes five suborders, namely Cryptobranchoidea, Ambystomoidea, Salamandroidea, Proteida and Meantes.

3. *Salientia* (or *Anura*)—e.g., *Bufo*, *Alytes*, *Rana*.

The order Salientia has five suborders under it. The suborders are: Amphicoela, Opisthocoela, Anomocoela, Procoela and Diplasiococla.

EXAMPLE OF AMPHIBIA—TOAD

Bufo melanostictus is a common toad. It is found in damp places all over this country. Toad represents the typical example of the class Amphibia. Despite the fact that toad is a highly specialised form amongst the living amphibians, it is studied extensively to gain an elementary knowledge on the anatomy of vertebrate in general and an amphibian in particular.

HABIT AND HABITAT

Toad is a cold-blooded or poikilothermous (i.e., the temperature of the body depends on the environmental temperature) vertebrate. Because of this fact, toad enters into the phase of winter sleep during colder months. This phenomenon is called the *hibernation*. Adult toad generally lives on land, but if necessary they can live in water for long time. Toad spends its early phase of life in water. It is truly an amphibian both in biological as well as literal sense (*amphi*=both; *bios*=life). Toad is quite at home in water as well as on land. On land it is obligatory for the toad to remain in dark and moist places, preferably near water. Skin of toad is an accessory respiratory organ and so it is kept moist. It tries to keep itself away from bright light. Toad is a carnivorous animal and catches insects by its sticky tongue. The males can produce croaking sound by the vocal sac, especially during breeding season. Toad breeds in water.

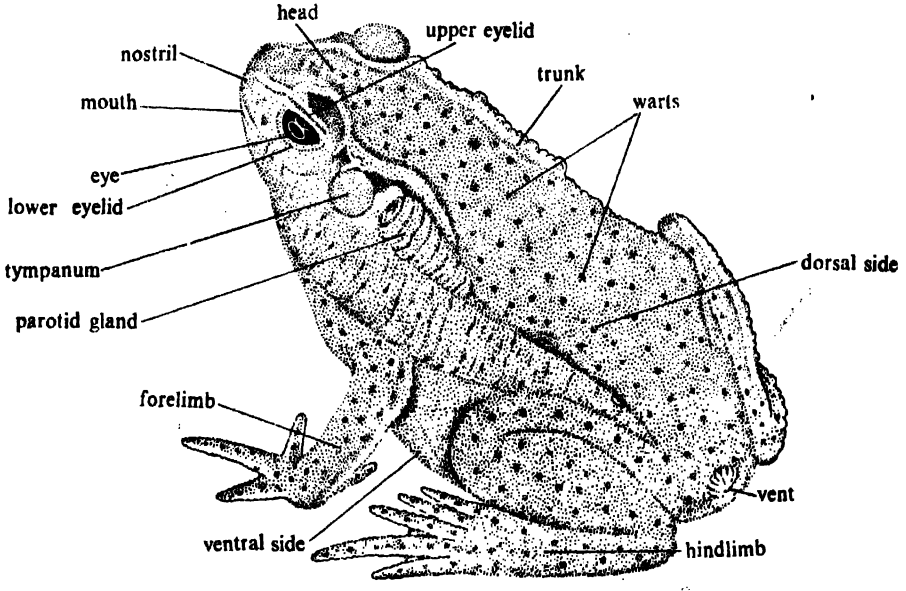


Fig. 6.2. Showing an adult *Bufo* in a sitting posture. Note the warty skin, paired parotid glands, bulging eyes and elongated hindlimbs.

EXTERNAL STRUCTURES

Toad has a short bilaterally symmetrical body (Fig. 6.2). There is no exoskeleton over the skin, i.e., the skin is naked. The skin has a rough texture. The dorsal side of the body is blackish grey while the ventral side is yellowish grey. Toad can change the colour of the body to match with the hues of its surroundings. Ordinarily it has a colour same as the earth. The body is divisible into the *head* and *trunk*. Distinct neck is absent. The post anal tail is absent in adult stage. Tail is present and well-developed in the larval condition. The head is semicircular in outline. It is broad, depressed and has a blunt *snout*. The *mouth* is an extraordinary wide opening located at the terminal end of the head. At the anterior dorsal side of the head there is a pair of rounded openings known as the *nostrils* or *external nares*. The eyes are very large and prominent. These are protruding and are situated one on either side of the head. Each eye is provided with a thick *upper eyelid* and an ill-developed *lower eyelid*. A transparent *nictitating membrane* (or third eyelid) is present which is stretched to cover the eyeball. Behind each eye, a circular area known as *ear drum* (or *tympanum*) is present. Just behind each tympanum there is an elongated elevation called the *parotid gland*. These paired glands secrete whitish pungent sticky juice. It is a poisonous secretion and causes nausea and effects the heart in man, if swallowed. When the secretion falls in the eyes and nose, it causes irritation, but rarely affects the skin. These glands act as the organs of offence and defence. The skin on the floor of the buccal cavity becomes inflated to form *vocal sac* in male. The trunk is broad, short and flattened. Ennumerable small elevations known as *warts* are present on the dorsal side of the body. The *cloacal aperture* or *vent* is located on the dorsal side of the posterior end of the body and between the two hindlimbs. There are two pairs of limbs. These are of unequal size. The forelimbs are smaller than the hindlimbs. Each forelimb consists of a *brachium* (upper arm), an *antebrachium* (fore arm) and a *manus* (hand). The hand is followed by four *digits*. In male individual, a cushion-like *thumb pad* (or *nuptial pad*) develops during breeding season at the basal part of index finger. These pads facilitate the male's grip during amplexus. The hindlimbs are strongly built and are much longer than the forelimbs. These two limbs are modified for jumping and swimming. Each hindlimb is composed of a proximal sector called *femur* (thigh) which is followed by *crus* (shank). Distal to the shank lies the *foot* (pes). The foot consists of a long tarsal region and five elongated slender digits. The digits are united by webs which help in swimming.

SKIN

The skin of toad is kept moist and frequently slimy. Besides its protective function, the skin of toad like that of other amphibians, serves as an additional respiratory organ. During hibernation, toad respires entirely by the skin.

The skin is composed of an outer *epidermis* and an inner *dermis* (Fig. 6.3). These two layers are separated by a basement membrane and a fibrous layer containing the *chromatophores*. The epidermis is a compound structure and is made up of several layers. The outermost layer is called the *stratum corneum*. It is a thin, scaly and cornified layer. This layer is dead and is shed periodically. This phenomenon of periodic renewal of the stratum corneum is called *ecdysis* (or *moulting*). In other amphibians the stratum corneum is thin and delicate, while in toad it is thicker and heavily cornified. The innermost layer of the epidermis is composed of columnar cells with prominent nuclei. This layer is called the *stratum germinativum* (or *Malpighian layer*) which sits on the basement membrane. Above the stratum germinativum, there are several layers of increasingly shorter cells finally grading into the flattened ones. These cells constitute the transitional layer.

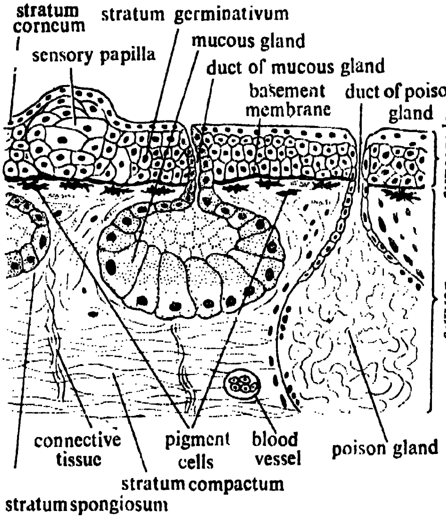
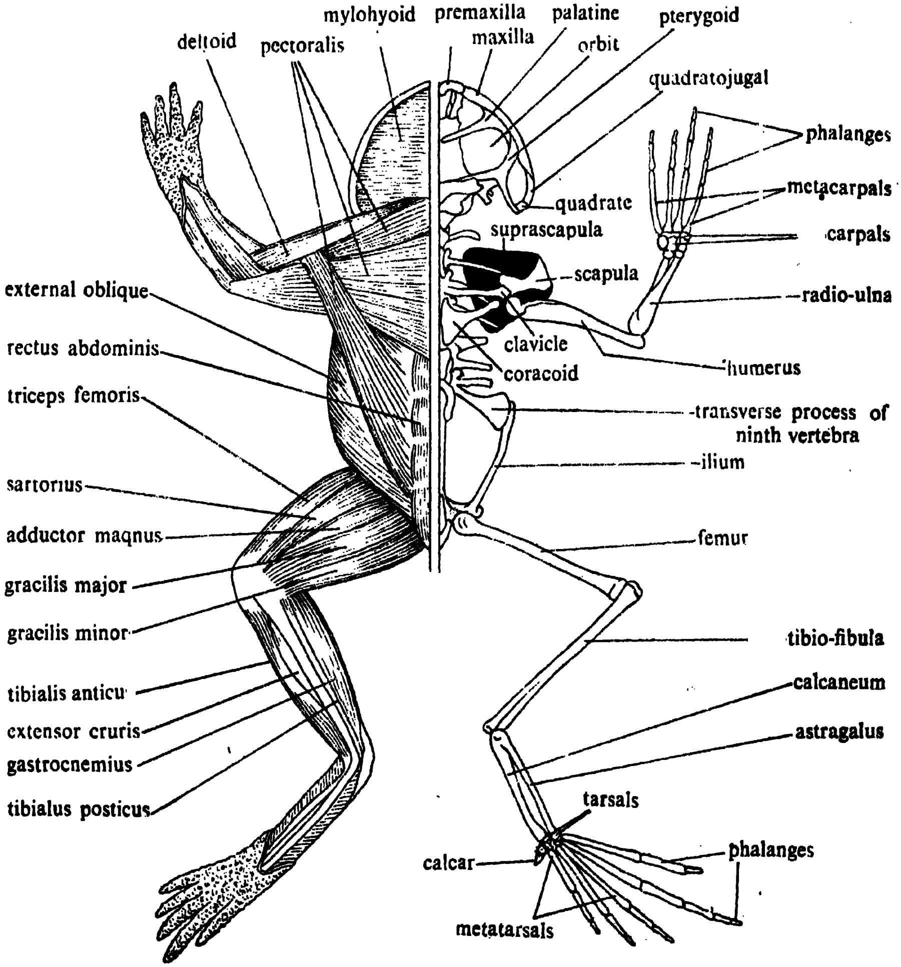


Fig. 6.3. Diagrammatic sectional view of skin of *Bufo*.

The dermis is thicker than the epidermis and is divisible into two layers. The outer layer housing most of the glands is called the *stratum spongiosum*. This is composed of loose network of connective tissue matrix with blood vessels and lymphatic spaces. The superficial part of this layer contains the pigment cells. The innermost layer is called the *stratum compactum* which is composed of dense connective tissue, smooth muscle fibres, nerves and blood vessels. Beneath the stratum compactum lies a loose subcutaneous connective tissue layer containing fatty tissue also.

The skin of toad is marked by the presence of numerous bumps (or warts) all over the body. These warts may be either due to underlying poison-glands or sensory papillae. There are two types of skin glands in toad. These are: (1) *Mucous glands* secreting the mucus and (2) *Poison glands* producing the poison. The mucous glands are smaller than the poison glands. The poison glands are composed of granular secretory cells. The skin glands usually lie in the stratum spongiosum of the dermis, but the poison glands may be more deeply located. These glands are ensheathed by the connective and muscular tissues, which help in squeezing the secretory products.

The colour of toad is due to the presence of pigment cells or chromatophores in the dermis. Some chromatophores also invade the epidermis. Depending on the types of contained pigment granules, the chromatophores may be *melanophores* (containing black pigment), *guanophores* (containing



mylohyoid
premaxilla
palatine
pterygoid
deltoid
pectoralis
maxilla
orbit
quadratojugal
phalanges
metacarpals
quadrate
carpals
suprascapula
scapula
radio-ulna
external oblique
clavicle
rectus abdominis
humerus
coracoid
triceps femoris
transverse process of ninth vertebra
ilium
sartorius
adductor maqnus
femur
gracilis major
gracilis minor
tibio-fibula
calcaneum
tibialis anticu
extensor cruris
astragalus
gastrocnemius
tarsals
tibialus posticus
phalanges
calcar
metatarsals

Fig. 6.4. Showing the muscular and skeletal systems of *Bufo*. The left half of the diagram indicates the disposition of the important skeletal muscles and the right half shows the skeletal framework.

colourless crystals of guanine) and *lipophores* (containing yellow pigment). The melanophores are situated in the deepest layer, the guanophores are intermediate in position, the lipophores overlying both these pigment layers. The melanophores are responsible for the production of blackish colour and the lipophores cause yellowish effect. The guanine crystals in the guanophores produce the diffraction effect. The colour change in toad is rather a slow process and is controlled by variation in the secretion of the pituitary gland. Absence of direct control of colour changes by the nerves in toad is a peculiar phenomenon. In fishes, instantaneous colour change is caused by the nerves while the slower change is under hormonal control.

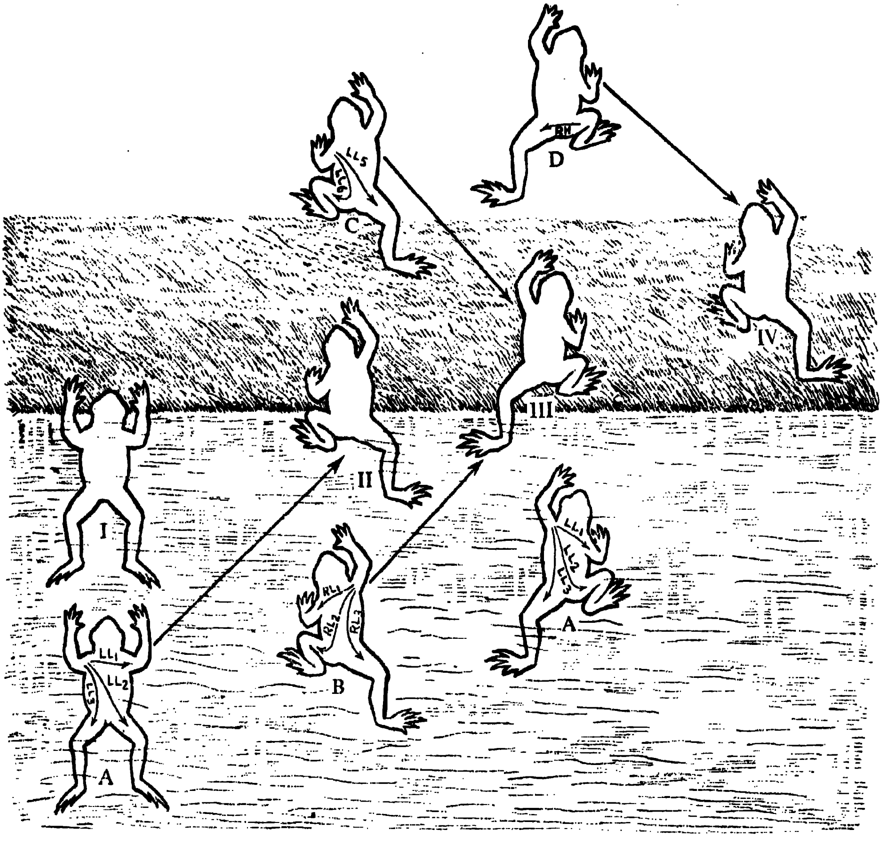


Fig. 6.5. Schematic representation of the different reflex actions involved with the transition from swimming to walking movement in *Bufo* (after Young). When a *Bufo* comes to land from water, first effective contact is made by the left forelimb (A) which elicits a crossed protractor reflex to the right forelimb (LL_1), a diagonal extensor response to the right hindlimb (LL_2) and a placing reflex to the left hindlimb (LL_3). The right forelimb then touches the ground and produces the responses $RL_1 \rightarrow RL_3$ as in B. After this contact the left forelimb produces retraction of the left hindlimb (LL_5) and protraction of the right hindlimb (LL_6) as in C. After that the right hindlimb produces cross flexor response (RH) as in D. I. First contact. II. Second contact. III-IV. Subsequent contacts.

MUSCULAR SYSTEM

The muscular system is composed of muscles which are used primarily for the movement of the body. There are three types of muscles: (1) Striated muscles, (2) Unstriated muscles and (3) Cardiac muscles. The striated muscles can be contracted at will and are attached to the skeleton. These muscles form the main mass of the external musculature. There are about two hundred skeletal muscles in the body of toad and the important ones are shown in Fig. 6.4. The muscles possess the power of contraction and relaxation. All the muscles are mostly arranged in opposing groups in such a fashion that when one set contracts, the opposing set remains in a relaxed state. This co-ordination is controlled by the nervous system.

LOCOMOTION

In toad, the entire muscular and skeletal system has become specialised for jumping and swimming. The movements are caused by the thrust of both the hindlimbs. Besides jumping and swimming, toad is able to walk on land. This is caused by bringing into play a set of proprioceptor reflexes as shown in Fig. 6.5.

In resting state, the anterior part of the body is inclined upwards and is supported by the forelimbs. The posterior part of the body is supported on the hindlimbs. The hindlimbs are folded in the manner of "Z". From such a sitting or squating posture, toad jumps by a sudden extension of the hindlimbs. The forelimbs manipulate and adjust the direction before each jump. Swimming is done by the activity of the limbs which act as the propellors. The hindlimbs are long and the digits are webbed. These limbs act like oars and enable the animal to swim.

SKELETAL STRUCTURES

There is no exoskeleton in toad. The skeleton that supports the soft parts lies internally and is designated as the endoskeleton. It is chiefly made up of bones and cartilages. These two structures are joined with one another to form the internal framework. The endoskeleton is described under two broad heads: (1) the axial skeleton and (2) the appendicular skeleton.

AXIAL SKELETON

The axial skeleton comprises of the skull and the vertebral column.

Skull. The skull of toad is flat and broad. It contains a tubular cranium and is pierced posteriorly by a large aperture called the *foramen magnum*. Through this aperture passes the spinal cord. On each side of this foramen there is an *exoccipital* bone which bears a convex *occipital condyle*. So there are two occipital condyles which fit into the two concavities of the first vertebra. The roof of the cranium is made up of two flat bones called the *frontoparietals*. Each frontoparietal is formed by the fusion of two bones, the frontal and parietal (Fig. 6.6A). The floor is formed of a dragger-like *parasphenoid*. A ring-like *sphenethmoid* bone is present at the anterior end of the cranium. This bone is completely covered by frontoparietals on the dorsal side. The nose is covered dorsally by a triangular *nasal bone* and the floor is provided with the *vomer* (Fig. 6.6B). The cartilaginous *optic capsules* are loosely attached with the cranium. The *auditory capsules* are situated in front of the exoccipitals. The floor of the auditory capsule is supported by the lateral extension of the *parasphenoid* and the dorsal side is covered by *prootic* bone. A small hammer-like *squamosal* connects the posterior part of the upper jaw with the otic capsule. Each half of the upper jaw is made up of small *premaxilla*, long slender *maxilla*

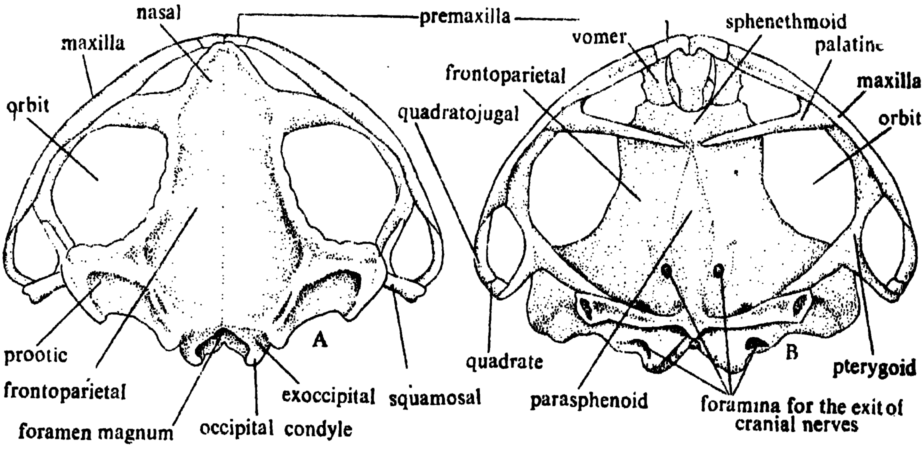


Fig. 6.6. Skull of *Bufo*. A. Dorsal view. B. Ventral view.

and *quadratojugal*. Behind the quadrotojugal there is a very small Y-shaped supporting bone called the *quadrate*. The other two supporting bones are the *pterygoid* and the *palatine*. The palatine is rod-like and connects the maxilla with the *sphenethmoid* bone. The lower jaw is composed of two halves and are united anteriorly by ligament (Fig. 6.7A). Each half is developed from a *Meckel's cartilage* and consists of three bones, the *dentary*, *angulosplenial* and *mento-meckelian*. The posterior part of the angulosplenial articulates with the upper jaw. Both the upper and lower jaws are toothless in toad.

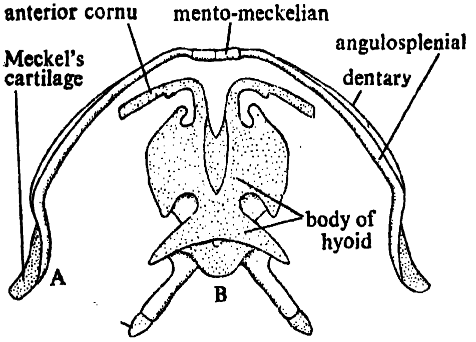


Fig. 6.7. A. Structure of the lower jaw of *Bufo*. B. Hyoid apparatus of *Bufo*.

Hyoid apparatus. The hyoid apparatus is essentially a cartilaginous body which supports the floor of the buccal cavity (Fig. 6.7B). It also forms the supporting framework for the attachment of the tongue. The body of the hyoid constitutes the main bulk of the apparatus. There are two pairs of prolongations (or *horns*) from the body of hyoid apparatus. The anterior pair is longer and extends upto the auditory capsules. These are called the *anterior cornua*. Similar pair on the posterior side is known as the *posterior cornua* which encloses the laryngotracheal chamber.

Vertebral column. The vertebral column (Fig. 6.8A) is composed of nine vertebrae and a terminal rod-like structure called the *urostyle* (*oura* = tail and *style* = rod).

Typical vertebra. A typical vertebra has a solid cylindrical part known as the *centrum*. The centrum is procoelous, i.e., the centrum is concave anteriorly and convex posteriorly (Figs. 6.8 C_1, C_2). On the dorsal side, the centrum bears a ring like *neural arch* which encloses the *neural canal*. The roof of the neural arch possesses a median elevation known as the *neural spine*. The lateral side the neural arch carries *transverse processes*. The articulating processes are present on the neural arch. The anterior processes are known as the *prezygapophyses* and the posterior pair is called the *postzygapophyses*. All the vertebrae excepting the first and the last ones have typical structural construction. But in Frog the eighth vertebra is peculiar by having amphicoelous centrum.

First Vertebra or Atlas. It articulates with the occipital condyles of the skull. It has a ring-like appearance (Fig. 6.8B). The transverse processes and the prezygapophyses are absent. Anteriorly it possesses two concave facets which fit with the paired occipital condyles of the skull. The centrum is greatly reduced.

Ninth Vertebra. This vertebra is peculiar by having two rounded condyles on the posterior side of the centrum for articulation with the concavities of the urostyle. The transverse processes are stout, fan-shaped and articulate with the pelvic girdle (Fig. 6.8 D_1, D_2). The postzygapophyses are absent. In Frog the transverse processes are not fan-shaped but are cylindrical.

Urostyle. The urostyle is a long slender rod-like structure (Fig. 6.8 E_1, E_2) and is formed by the fusion of a number of vertebrae. It has a pair of concave cavities for articulating with the paired posterior convexities of the ninth vertebra. It has a middorsal neural crest. A very narrow hole is present throughout the urostyle which represents the reduced neural canal. Through this canal passes the *filum terminale* of the spinal cord.

APPENDICULAR SKELETON

The skeletal frame of the paired limbs and the girdles constitute the appendicular skeleton (Fig. 6.9).

Pectoral girdle. The pectoral girdle consists of two symmetrical halves. These halves are united at the midventral line but are free dorsally (Fig. 6.9B). This girdle forms a bony framework for encircling the anterior part of the trunk. Each half of the pectoral girdle is made up of a broad dorsally placed and partly cartilaginous plate-like structure known as *suprascapula*. Attached to it, there is a strong bone called *scapula*. Two rod-like bones are connected with the scapula. The anterior one is called the *clavicle*, while the posterior one is known

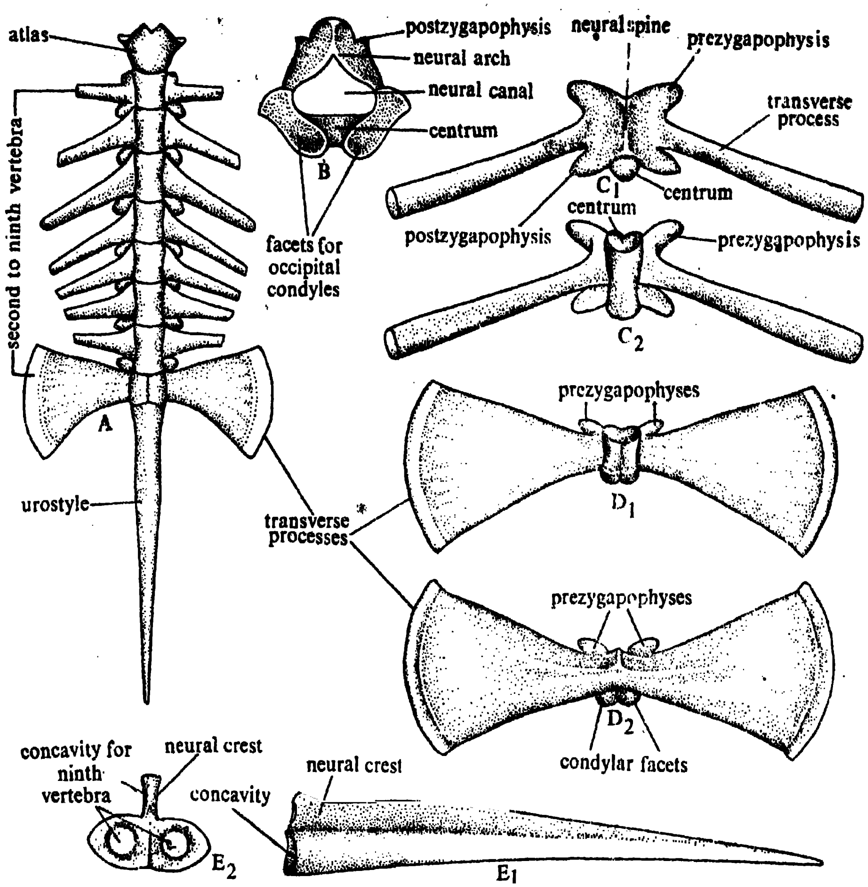

atlas
second to ninth vertebra
A
urostyle
postzygapophysis
neural arch
neural canal
centrum
B
facets for occipital condyles
neural spine
prezygapophysis
transverse process
C1
centrum
postzygapophysis
centrum
prezygapophysis
C2
prezygapophyses
D1
transverse processes
prezygapophyses
D2
condylar facets
concavity for ninth vertebra
neural crest
concavity
E2
neural crest
E1

Fig. 6.8. Structure of vertebral column of *Bufo*. A. Ventral view of entire vertebral column. B. First vertebra. C_1. Dorsal view of a typical vertebra. C_2. Ventral view of a typical vertebra. D_1. Ventral view of ninth vertebra. D_2. Dorsal view of ninth vertebra. E_1. Side view of urostyle. E_2. Anterior end view of urostyle.

as the *coracoid*. The clavicle encloses the *precoracoid cartilage* which is hardly visible. The clavicle and the coracoid are joined with partly overlapping pieces, the *epicoracoids*. The space present between these three bones is designated as the *coracoid frontanella*. Just at the junction of the clavicle, coracoid and scapula there is a cup-shaped *glenoid cavity* into which fits the head of the humerus. Projecting posteriorly from the united posterior end of the epicoracoid there lies a *sternum* which has a terminal flattened cartilaginous *xiphisternum*.

Pelvic girdle. The pelvic girdle is a V-shaped bony structure having a disc-like posterior end. The disc is formed by the union of three bony units on each side, the *ilium*, *ischium* and *pubis* (Fig. 6.9D). A cavity known as *acetabulum* is present on each side of the disc. The head of the femur fits into this cavity. The ilia are elongated curved rod-like structures which are attached with the transverse processes of ninth vertebra. Two pubes are represented by a triangular cartilage on the ventral side of the disc.

Forelimbs. There are two forelimbs and each forelimb is composed of several long bones arranged end to end (Fig. 6.9A). The first one is called the *humerus* whose middle region is slightly curved. The proximal end is termed as the head of the humerus which fits with the glenoid cavity of the pectoral girdle. The posterior end carries a pulley-like *trochlea*. A prominent crest called the *deltoid ridge* is extended from the head to the middle region of the humerus. The second sector is the *radioulna* formed by the fusion of two separate bones, radius and ulna. The anterior end of the radioulna is concave and fits with the trochlea of the humerus. The proximal end is drawn out into an *olecranon process*. The other end is flattened to give attachment of six *carpal bones* which are arranged in two rows. Four slender rod-like bones called *metacarpals* are connected with the digits. There are four digits. The third and fourth digits have three phalanges and the first and second have two phalanges.

Hindlimbs. The hindlimbs, like the forelimbs, are also paired structures. Each is made up of series of long bones (Fig. 6.9C). The proximal one is the *femur* which is gently curved. The anterior end of the femur is rounded to form the head of the femur and the posterior end is slightly flattened to form the *condyle*. The next part is known as the *tibiofibula* formed by the fusion of two bones, the *tibia* and *fibula*. Both the ends of the tibiafibula are expanded to give articulation with the condyle of the femur anteriorly and with the *tarsal bones* distally. The tarsal bones are arranged in two rows. The proximal tarsals are the *astragalus* and the *calcaneum*. These are elongated structures and are slightly curved outward. Both the astragalus and calcaneum are joined with one another at both ends. The distal tarsals are composed of two or three small bones. The foot is constituted of five *metatarsals*. There are five digits having variable number of phalanges. A bony projection made up usually of two small bony nodules is present on the outer side of the *hallux*. This structure is known as the *prehallux* (or *calcar*).

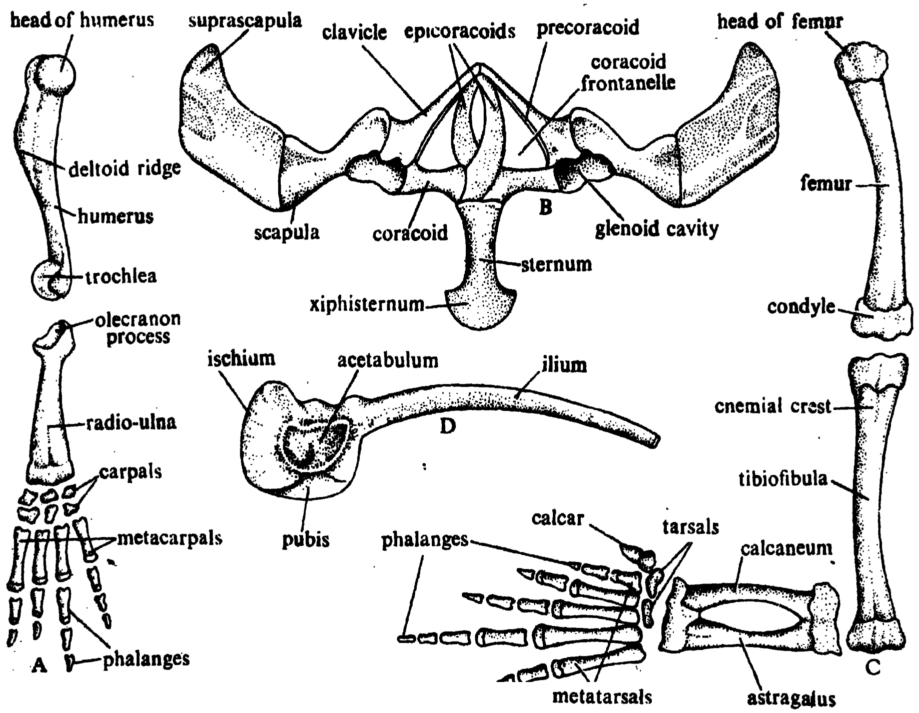

head of humerus
suprascapula
clavicle
epicoracoids
precoracoid
head of femur
coracoid frontanelle
deltoid ridge
humerus
trochlea
scapula
coracoid
B
glenoid cavity
femur
sternum
xiphisternum
condyle
olecranon process
ischium
acetabulum
ilium
radio-ulna
D
cnemial crest
carpals
tibiofibula
calcar
tarsals
metacarpals
pubis
phalanges
calcaneum
phalanges
A
metatarsals
astragalus
C

Fig. 6.9. Appendicular skeleton of *Bufo*. A. Bones of the left forelimb. B. Ventral view of the pectoral girdle. C. Bones of the left hindlimb. D. Side view of pelvic girdle (right half).

COELOM

The coelom is a large and undivided cavity. The internal organs or *viscera* are lodged in the coelom. The coelom is lined by the coelomic epithelium called the *peritoneum*. The peritoneum also encircles the alimentary canal and other organs. These visceral organs are suspended to the body wall by the fan-shaped folds called the *mesenteries*. The pericardial cavity housing the heart is a coelomic derivative which becomes cut off from the main coelom and exists as a separate cavity.

DIGESTIVE SYSTEM

The digestive system consists of *alimentary canal* and the associated *digestive glands*. This system is primarily concerned with the process of nutrition. The digestive glands secrete enzymes which help in digestion and the alimentary canal performs the rest of the functions.

The alimentary canal is a long tube which starts from the mouth and ends in the anus. This canal has a basic histological picture throughout its length and becomes regionally modified to perform certain specific functions.

The alimentary canal is made up of four layers. The outermost layer is thin and called the *serous coat*. Next to the serous coat lies the *muscular layer* which is composed of an outer *longitudinal muscles* and the inner *circular muscles*. The innermost layer lining the lumen is the *mucous coat*. The mucous layer is composed of epithelial cells and glands in certain regions. The region between the muscular coat and the mucous coat is filled up with connective tissue matrix with blood and lymphatic vessels. This layer is known as the *submucous coat*.

The *mouth* is a wide aperture and is bounded by upper and lower jaws. Both the jaws are toothless. The mouth leads into a spacious *buccal cavity*. The roof of the buccal cavity contains a pair of *internal nostrils*, impressions of the *eyeballs*, a pair of *eustachian apertures*. The floor of the buccal cavity bears a large fleshy tongue. The tongue is very peculiar, because it is fixed anteriorly but free behind. The tongue is kept sticky by the secretion of intermaxillary glands. It can quickly be protruded to capture insects (Fig. 6.10). Below the tongue there is a longitudinal slit called the *glottis* which leads into the *laryngotracheal chamber*. There are mucous glands in the buccal cavity which do not produce any enzyme. There is a system of cilia in the buccal cavity which possibly keep the oral fluids in circulation. The buccal cavity narrows towards the *pharynx* which leads into a wide tube known as the *oesophagus* or *gullet*. The oesophagus opens into the *stomach*. The stomach is a thickwalled spacious sac and is slightly curved (Fig. 6.11A). The broad anterior part of the stomach is known as *cardiac end* and the other end is called *pyloric end*. The pyloric part of the stomach opens into *intestine*. This opening is guarded by circular sphincter muscle called the *pyloric valve* which regulates the exit of food from the stomach. The mucous coat of the stomach contains tubular *gastric glands* which secrete digestive juices and the unicellular *parietal glands* (or *oxyntic cells*) which secrete hydrochloric acid. In addition to the longitudinal and circular muscle layers in the muscular coat, *oblique muscles* are also present in the stomach. The part of the intestine next to stomach is known as *small intestine* which is again divided into an anterior short *duodenum* and posteriorly into an *ileum*. The duodenum receives duct from liver and pancreas. The ileum is extensively coiled and is held in position with the body wall by *mesentery*. The mucous coat of the ileum gives off numerous finger-like elevations known as the *villi* which increase the inner surface areas. In addition, it contains *intestinal glands* which secrete *intestinal juices*. The portion of alimentary canal next to ileum is usually called the *large intestine* which is divided into the *rectum* and *cloaca*. The cloaca is a common chamber where urine, gametes and faecal matters are temporarily stored. The cloaca opens to the exterior through the *vent* (or *cloacal aperture*).

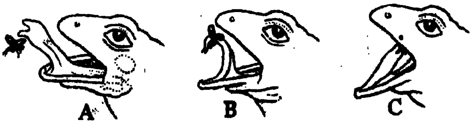


Fig. 6.10. Showing the mechanism of catching an insect by the manipulation of tongue in *Bufo*.

Besides the gastric and intestinal glands, the *liver* and the *pancreas* are the important digestive glands. The liver is the largest gland and consists of two main lobes, left and right lobes connected with one another by a bridge. The left lobe of the liver is the largest and is subdivided into two lobes. The secretory as well as the excretory products of the liver is called the *bile*. The bile comes out by *hepatic ducts* and is stored in the *gall bladder*. The *cystic duct* from the gall bladder and the hepatic duct from the liver unite to form the *common bile duct*. This common bile duct passes through pancreas and receives numerous minute *pancreatic ducts*. The common bile duct is usually called the *hepatopancreatic* duct which ultimately opens into duodenum to pour the hepatopancreatic juices into the duodenal cavity. Fig. 6.11B shows the relationship of the liver and pancreas with the duodenal part of the intestine. The pancreas is an irregular and yellowish gland. It is a both exocrine as well as endocrine gland. The exocrine part secretes the *pancreatic juice*. The endocrine part, *islets of Langerhans*, produces a hormone known as *insulin*.

cannot be absorbed unless these are broken down into simpler forms. Digestion is caused by the digestive juices. These juices contain specific enzymes which act on a specific type of food by causing *hydrolysis* (i.e., chemically, addition of a molecule of water with a molecule of the substance upon which enzymes act). Three groups of enzymes are present: (1) *Amylolytic* or *diastatic enzymes*, such as the *amylase* of the pancreatic juice, (2) *Lipolytic enzyme*, the *lipase* of the pancreatic juice and (3) *Proteolytic enzymes*, viz. the *pepsin* of gastric juice, the *trypsin* of pancreatic juice, *erepsin* of the intestinal juice. Thoroughly mixed with

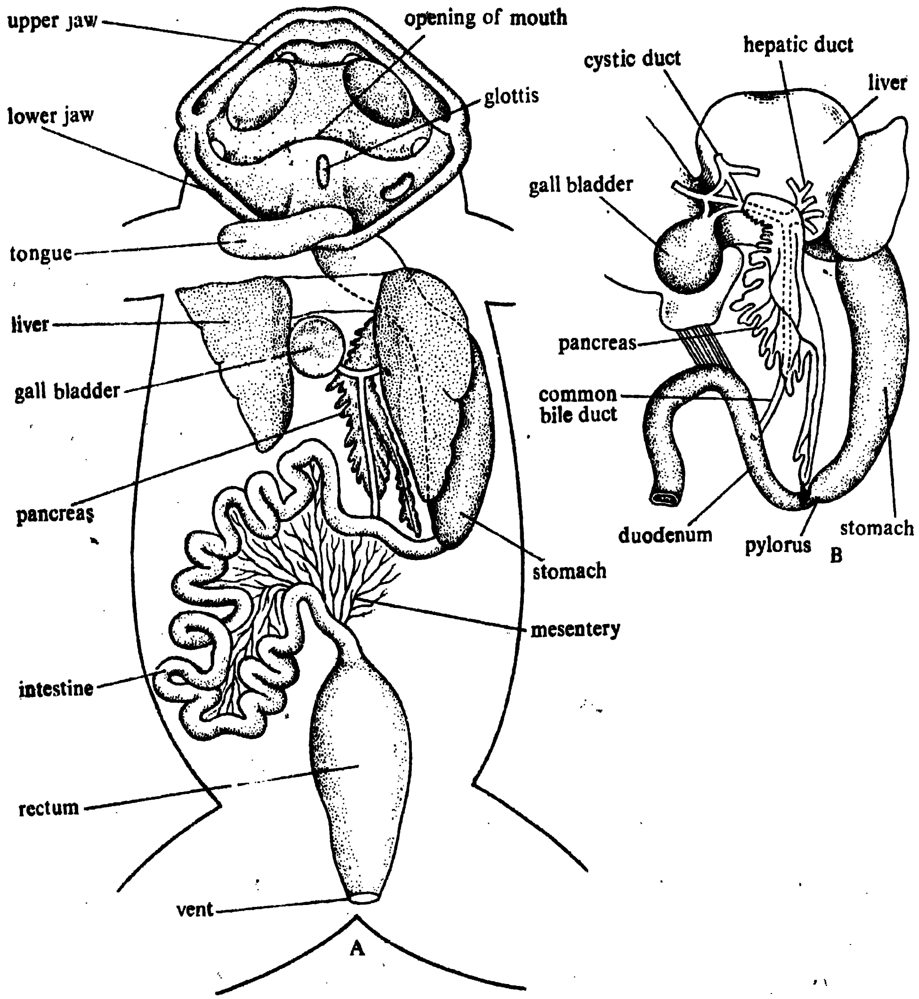

upper jaw
opening of mouth
lower jaw
glottis
tongue
liver
gall bladder
pancreas
intestine
rectum
vent
stomach
mesentery
A
cystic duct
hepatic duct
liver
gall bladder
pancreas
common bile duct
duodenum
pylorus
stomach
B

Fig. 6.11. A. Digestive system of *Bufo*. B. Showing the relationship of th lobes of the liver, pancreas and their respective ducts with the duodenum in *Bufo*.

Physiology of digestion

Toad is a carnivorous animal which feeds on small animals, preferably the insects. The food consists primarily of the carbohydrates, proteins, fats, vitamins, mineral salts and water. The vitamins, mineral salts and water are absorbed as such but the carbohydrates, proteins and fats are complex organic compounds which mucus in the buccal cavity, the food comes into the stomach. The parietal glands or the oxyntic cells in the mucous coat of stomach secrete the hydrochloric acid. In the acidic medium, the pepsin acts on the proteins and converts them into *peptones.* After remaining for sometime in the stomach, the half digested *acid chyme* passes into the duodenum where it comes in contact with the bile. The bile being alkaline, neutralises the acid. The trypsin then converts the *peptones* into the soluble *amino acids* which are readily absorbable. The *erepsin* of the intestinal juices quickens the process of conversion. The lipase converts fats into the soluble *fatty acids* and *glycerine.* The amylase of pancreatic juice and the maltase of the intestinal juice convert *starch* into *glucose.* The soluble food is absorbed and assimilated into the body and the undigestible products are egested as the faeces through vent. The surplus glucose is converted into *glycogen* and stored in liver and skeletal muscles. The fatty acids are transformed into fat and stored in the body as the fat bodies. The amino acids are not stored, the excess being transformed into the *urea* and excreted through the urine.

SPLEEN

The spleen is a ductless glandular body of dark-red colour. It is spherical in shape and remains morphologically connected with the mesentery near the junction of the ileum and the rectum. The spleen acts as a store house of blood and also destroys old and worn out erythrocytes.

RESPIRATORY SYSTEM

Respiration is essentially a physico-chemical process of taking in of oxygen and giving out of carbon dioxide and water. During this process, the stored food within the cells becomes slowly oxidised. During the process of oxidation energy is liberated in the form of calories which are necessary for the vital activities. The carbon dioxide and water vapour are given out during the process.

MODES OF RESPIRATION

Toad is truely an amphibious animal in strict sense. As a result, two modes of respiration are observed. Terrestrial respiration involves the utilisation of oxygen present in atmospheric air and in aquatic respiration the oxygen dissolved in water is used.

TERRESTRIAL MODE OF RESPIRATION

Toad is capable to breathe air by the lungs and skin.

Pulmonary respiration. The buccal cavity communicates into the *laryngotracheal chamber* (or voice-box) through a slit-like glottis. The laryngotracheal chamber is a stout box-like structure with two elastic vocal cords stretching across the cavity (Fig. 6.12A). The wall of the laryngotracheal chamber is supported by the *arytenoid* and *cricoid* cartilages. Sound is produced by the vibration of the vocal cords which also control the intensity and pitch of the sound. The vocal sac in male helps to intensify the sound by acting as the resonator. The laryngotracheal chamber gives off two extremely short *bronchi.* Each bronchus opens into a thin-walled spongy *lung.* Internally, the lungs have innumerable simple sacs (Fig. 6.12B) known as the *alveoli* (or *air-sacs*). Each alveolus is a highly vascular structure and the alveolar epithelia are actually the seats of exchange of gases.

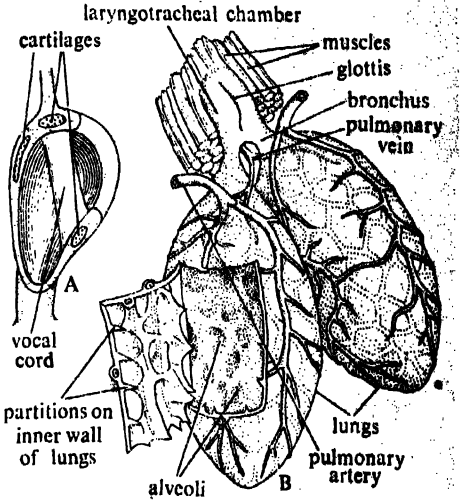


Fig. 6.12. Respiratory system in *Bufo.* A. Laryngotracheal chamber is cut to show the vocal cord. B. Structure of the lungs. A portion of the lung is dissected to show the alveoli.

PHYSICAL MECHANISM OF PULMONARY RESPIRATION. The physical mechanism of pulmonary respiration involves three successive stages, aspiration, expiration and inspiration (Fig. 6.13).

Aspiration. During the process toad closes its mouth but the external nostrils are kept open. The floor of the buccal cavity is then lowered. As a result of lowering of the floor, partial vacuum is created and thus fresh atmospheric air is rushed into the buccal cavity. The glottis remains closed, so the air can not enter the lungs.

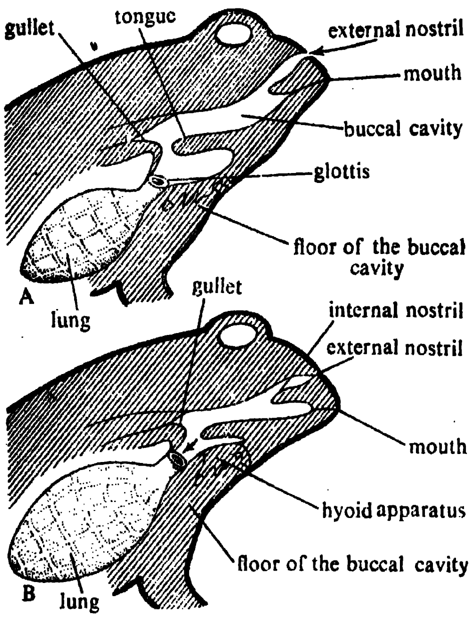


Fig. 6.13. Schematic representation of the physical mechanism of respiration in *Bufo*. A. Aspiration which is followed by expiration. B. Inspiration.

Expiration. Aspiration is quickly followed by expiration. The trunk muscles contract upon the lungs and cause the expulsion of air from the lungs to the buccal cavity through glottis. This expelled air is rich in carbon dioxide. As a result of inhaled and expelled air, the buccal cavity becomes highly distended. Mixture of these two types of air now goes out through open nostrils.

Inspiration. Expiration is immediately followed by inspiration. The external nostrils are then tightly closed and the floor of the buccal cavity is raised forcibly as a result of which mixed air from the buccal cavity is pushed into the lungs through glottis. The hyoid apparatus plays an important role in lowering and raising the floor of the buccal cavity.

Buccopharyngeal respiration. The mucous membrane lining the buccopharyngeal cavity is always kept moist and is highly vascular. Through this membrane exchange of gases occurs normally.

Cutaneous respiration. As already stated, the skin of toad is moist and richly supplied with the blood vessels. It acts as an additional respiratory organ. The cutaneous breathing is a continuous process and is very important specially during hibernation.

AQUATIC RESPIRATION

The early phase of the life-cycle of toad is passed in water. The tadpoles are the larval forms which respire by means of *external* and *internal gills* in addition to the skin. The external gills are the epithelial extensions and contain blood capillaries. The gills can absorb oxygen dissolved in water and gives out carbon dioxide.

Exchange of gases. The oxygen is conveyed to the different tissues by the blood. The oxygen combines with the *haemoglobin* to form an unstable compound *oxyhaemoglobin*. In this state, oxygen reaches the cells and the oxyhaemoglobin on reaching the places releases the oxygen and regains its former state. This circle is repeated. The carbon dioxide is transported by the blood plasma in the form of bicarbonates and finally expelled through the respiratory surface.

CIRCULATORY SYSTEM

The circulatory system comprises of two systems: the blood vascular system and the lymphatic system. Circulatory system is the internal transport system by which nutritive materials, waste products and oxygen are conveyed to the different parts of the body. The circulatory system of toad is well-developed. This system is composed of three main components: blood, heart and blood vessels.

BLOOD

The blood is the main circulatory fluid. It consists of a straw-coloured blood *plasma* and different *blood corpuscles* suspended in the plasma. The plasma is a watery liquid and contains many mineral salts, food, wastes and hormones. The corpuscles are of three types. These are: (1) *Red blood cells* (R.B.C. or *erythrocytes*), (2) *White blood cells* (W.B.C. or *leucocytes*) and (3) *Thrombocytes* (or *blood plate lets*). The erythrocytes are oval, biconvex and nucleated cells ranging from 15 to 20 micra in size. They contain the red coloured iron-containing protein, the *haemoglobin*. The haemoglobin has a lower affinity for oxygen than that of higher forms, specially the mammals. The leucocytes are colourless, nucleated and amoeboid cells. They are phagocytes and destroy bacteria and thus protect the animal from the invading microbes. The thrombocytes or blood plate lets are small spindle-shaped nucleated cells and play an important role in the process of coagulation of blood. When there is shedding of blood, plate lets release a particular type of enzyme which helps in coagulation.

HEART

The heart is the central pumping organ in the circulatory system (Fig. 6.14). In toad, it is a pear-shaped muscular structure situated in the anterior part of the body cavity. It remains enclosed by a transparent protective membrane called the *pericardium*. The space between heart and the pericardium is called the pericardial cavity. The heart of toad is composed of the following parts: (1) *Receiving parts*. Two *auricles* and a *sinus venosus* are the receiving parts of the heart. (2) *Forwarding parts*. The *ventricle* and the *conus arteriosus* are the forwarding parts of the heart. (3) *Intercommunicating appertures* and *valves* between the different parts of the heart. The auricles are two in number and are of unequal size. Both the auricles are sharpedly marked off from the ventricles by a narrow constriction called the *coronary sulcus*. The left auricle is smaller than the right auricle. The two auricles are completely separated by *interauricular septum*. The *sinus venosus* is a triangular thin-walled chamber formed by the union of three major veins, two *precavals* and one *postcaval* (Fig. 6.14A). It is situated on the dorsal side of the right auricle. It communicates with the right auricle through a *sinuauricular aperture* which is guarded by *sinuauricular valves*. Deoxygenated blood, collected in the sinus venosus from the precaval and postcaval veins, enters into the right auricle but the backflow is prevented by the sinuauricular valves. The left auricle receives oxygenated blood through a small opening of the *common pulmonary vein*. This aperture is also guarded by valves. The right and left auricles communicate to the ventricle by a common *auriculoventricular aperture*. This aperture is guarded by membranous valves known as the *auriculoventricular valves*. The free ends of the valves are attached with the wall of the ventricle by fine thread like *chordae tendineae*. The auriculoventricular valves give one-way traffic of blood from the auricles to ventricle. The *ventricle* is a highly muscular chamber. It is more or less conical in shape. Its cavity is greatly reduced

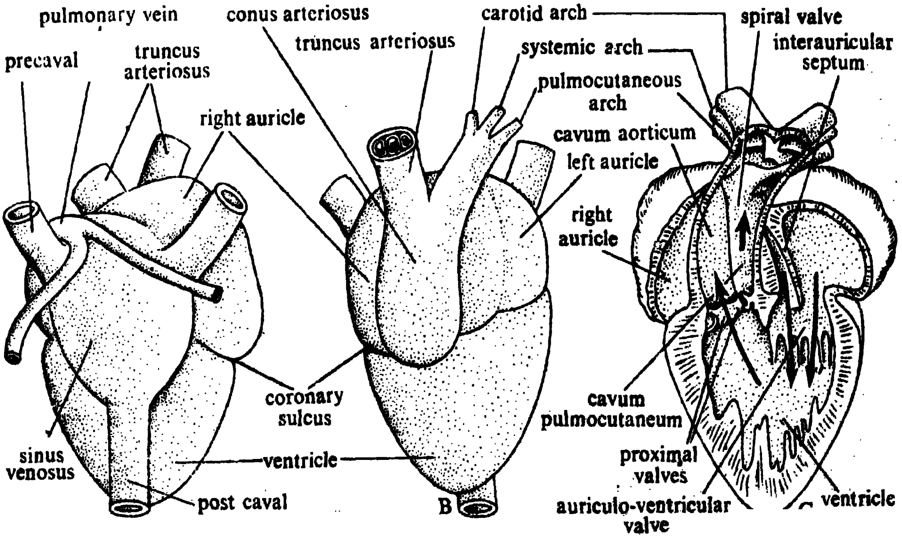

pulmonary vein
precaval
truncus arteriosus
conus arteriosus
truncus arteriosus
right auricle
carotid arch
systemic arch
pulmocutaneous arch
cavum aorticum
left auricle
right auricle
spiral valve
interauricular septum
coronary sulcus
sinus venosus
ventricle
post caval
B
cavum pulmocutaneum
proximal valves
auriculo-ventricular valve
ventricle

Fig. 6.14. Structure of heart of *Bufo*. A. Dorsal view. B. Ventral view. C. Diagrammatic longitudinal sectional view.

by a large number of interlacing muscles called the *columnae carnae*. The *conus arteriosus* is a stout tubular body situated on the ventral side of the heart (Fig. 6.14B). It is continued anteriorly into the *trunkus arteriosus*. The trunkus arteriosus is not to be considered as the part of heart, but as the basal stem of the three main arteries. It remains uncovered by the pericardium. A set of pocket-like semilunar valves demarkates the trunkus from the conus. A similar set of three semilunar valves guard the opening between the conus and the ventricle. These valves prevent backflow of blood from conus to the ventricle. A twisted longitudinal *spiral valve* divides the cavity of the conus into two channels. The left channel is designated the *cavum pulmocutaneum* and the right one is the *cavum aorticum* (Fig. 6.14C). The oxygenated blood passes through the cavum pulmocutaneum by the manipulation of the spiral valve.

MECHANISM OF CIRCULATION THROUGH THE HEART

Periodic contraction (systole) and relaxation (diastole) is an innate property of heart. During diastole, the sinus venosus drains the deoxygenated blood from the two precaval and one postcaval veins. The left auricle is also simultaneously filled up with the oxygenated blood from lungs carried through the common pulmonary vein. Just with the onset of systole, the sinus venosus contracts and the deoxygenated blood is rushed into the right auricle through sinuauricular aperture. So both the auricles are now filled up with blood, the left one is filled with the oxygenated blood and the right auricle is filled with the deoxygenated blood. After the auricles being filled up with the blood the auricular systole starts. Two auricles contract simultaneously and drive the contents into the ventricle through auriculoventricular aperture. Consequently two types of blood enter into the cavity of the ventricle where admixture of two types of blood takes place. Due to the spongy nature of the ventricular cavity, a major quantity of the deoxygenated blood is present in the right side, the left side contains mostly the oxygenated blood while the middle part contains mixed type of blood. But the experiments of Foxon (1955) by injecting X-ray opaque materials have shown that no separation of the oxygenated and deoxygenated blood actually occurs in the ventricular cavity. As the skin subserves respiratory function, the right auricle also receives oxygenated blood. The spongy ventricular walls presumably help in metabolic exchanges and have nothing to do in the separation of the types of blood. Next the ventricle starts contraction. The backflow of blood into the auricles is prevented by the auriculoventricular valves. The blood from the ventricular cavity finds the way through the conus. As the conus arises from right side, a large quantity of deoxygenated blood from the ventricle enters first. This blood is now conveyed through the cavum pulmocutaneum by the spiral valve. From the cavum pulmocutaneum blood goes to pulmocutaneous arteries for oxygenation. The deoxygenated blood is aerated in lungs and brought back to left auricle through common pulmonary vein and thus complete the '*pulmonary circuit*'. With the enhancement of contraction force of the ventricle, the mixed blood from the middle region of the ventricle is pushed into the systemic arches through the cavum aorticum. Lastly, the pressure exerted by the carotid labyrinth is overcome and mostly the oxygenated blood from the left side of the ventricle is forcefully pumped into the carotid arches. It is to be noted that the spiral valve directs the entry of blood into different arches.

BLOOD VESSELS

The *arteries* and *veins* are the blood vessels through which the blood circulates. These vessels are different in structure and function. The arteries take the blood away from the heart to different parts of the body and the veins return the same towards the heart. The arteries supply blood to the different parts and break up into finner branches, the *arterioles* which finally end into a network of *capillaries*. These capillaries again reunite to form small *venules*. The *venules* unite to form the veins. Histologically, a typical blood vessel is composed of three distinct layers. The outermost covering is made up of fibrous connective tissue known as the *tunica adventitia*. The middle layer is composed largely of involuntary muscles called the *tunica media*. The innermost layer is made up of endothelium and elastic fibres and is called the *tunica interna*. The differences between the arteries, veins and capillaries are given in Table Chordata-8.

TABLE—CHORDATA 8

Structures	Arteries	Veins	Capillaries
1. Tunica adventitia	Moderately developed.	Thicker.	Absent.
2. Tunica media	Thick and well-developed.	Thinner.	Absent.
3. Tunica interna	Elastic fibres are present.	Elastic fibres are absent.	This layer is only present and is composed of endothelium. The elastic fibres are absent.
4. Elasticity	Highly elastic.	Non-elastic.	Non-elastic.
5. Lumen	Proportionately smaller in diameter.	Larger in diameter.	Small.

ARTERIAL SYSTEM

The arteries and their branches constitute the arterial system (Fig. 6.15). The trunkus arteriosus divides into two main branches, each of which again splits up into three arches, (1) the anterior *carotid arch*, (2) the middle *systemic arch* and (3) the posteriormost *pulmocutaneous arch*.

Embryonic arrangement of the arterial arches. In the embryonic state, there are six pairs of arterial arches. Of these paired arches, the first and second pairs disappear in adult. The third pair is converted into the carotid arches. The fourth pair is transformed into the systemic arches. The fifth pair disappears and the sixth pair is present as the pulmocutaneous arches in adult.

Carotid arches. There are two carotid ararches in toad. Each carotid arch proceeds forward and outward. It soon divides into an outer branch called the *internal carotid artery* supplying blood to the brain, the meninges and into an inner branch called the *external carotid artery* which supplies blood to the outer side of the head, tongue and the buccal cavity. Just at the point of bifurcation, there is a small swelling known as *carotid labyrinth* (or *carotid gland*). The inner cavity of the carotid labyrinth contains a network of small vessels and forms a spongy structure. Though this structure is a receptor, it is physiologically connected with the regulation of the blood pressure. The internal carotid artery, after its origin, takes a backward course and comes very close to the systemic arch and is being tied with it by fibrous *carotid ligament*.

Systemic arches. There are two systemic arches in toad. Each systemic arch takes the median position and sweeps outward to surround the oesophagus. It then comes to the dorsal side and joins with its fellow of the opposite end to form the *dorsal aorta.* The following branches arise from each systemic arch: (1) A *laryngeal artery* which is very short and supplies the laryngotracheal chamber. (2) An *occipitovertebral artery* which gives branches to the pharynx, back of the head, vertebral column and spinal cord. (3) A stout *subclavian artery* supplies blood to the shoulder and forelimb. All these branches exhibit bilateral symmetry but the left systemic arch gives off an additional branch called the *oesophageal artery* which supplies blood to the oesophagus. This branch is not present in the right side. The *dorsal aorta* occupies the mid-dorsal position and is situated ventral to the vertebral column and ends posteriorly into two *iliac arteries*. The dorsal aorta gives off the following branches anteroposteriorly: (1) A stout *coeliacomesenteric artery* which emerges out just from the origin of the dorsal aorta. The artery immediately breaks up into a *coeliac* branch to supply blood to stomach, liver, gall-bladder and pancreas and a *mesenteric artery* supplying blood to the mesenterics, intestine, cloaca and spleen. (2) Four or five pairs of *renal arteries* supply the kidneys. From the anterior renal arteries, there arise additional branches for the gonads. These small branches are called the *genital arteries*,

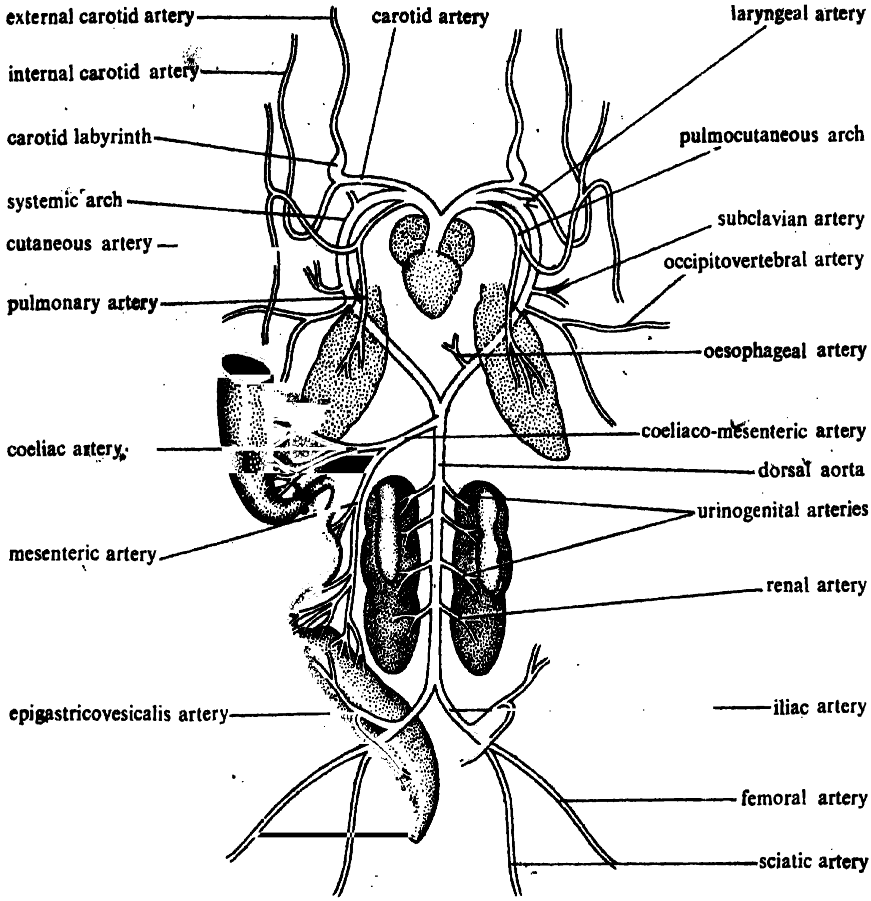

external carotid artery
carotid artery
laryngeal artery
internal carotid artery
carotid labyrinth
pulmocutaneous arch
systemic arch
subclavian artery
cutaneous artery
occipitovertebral artery
pulmonary artery
oesophageal artery
coeliac artery
coeliaco-mesenteric artery
dorsal aorta
urinogenital arteries
mesenteric artery
renal artery
epigastricovesicalis artery
iliac artery
femoral artery
sciatic artery

Fig. 6.15. Arterial system of *Bufo*.

(3) The *iliac arteries* are the last branches of the dorsal aorta. From each iliac artery an *epigastricovesicalis artery* is given off to supply the urinary bladder and the ventral body wall. The iliac artery then enters into the hindlimb and divides into *femoral* and *sciatic* arteries.

Pulmocutaneous arches. These are the shortest and the hindermost arches which carry deoxygenated blood to the lungs and skin. Each main arch enters into lung as *pulmonary artery* and a very slender branch from it goes to the skin as *cutaneous artery*.

VENOUS SYSTEM

The veins and their branches constitute the venous system (Fig. 6.16). The venous system of toad can be described under three headings: (1) systemic, (2) portal and (3) pulmonary.

Systemic veins. Three large veins or *venae cavae* which open into the sinus venosus represent the systemic veins. The systemic veins carry deoxygenated blood from almost all parts of the body excepting lungs. The anterior two venae cavae are known as the left and right *precavals* and the single posterior one is called *postcaval*. Each precaval vein is formed by the union of three branches. These are:

(i) *External jugular vein*, (ii) *Innominate vein* and (iii) *Subclavian vein*. The external jugular vein is formed by two veins, a *lingual* carrying blood from the tongue and a *faciomandibular* from the snout and jaws. The innominate vein is also formed by the union of two veins, an *internal jugular* bringing blood from the head and a *subscapular* from the back of shoulder. The subclavian vein is similarly formed by two

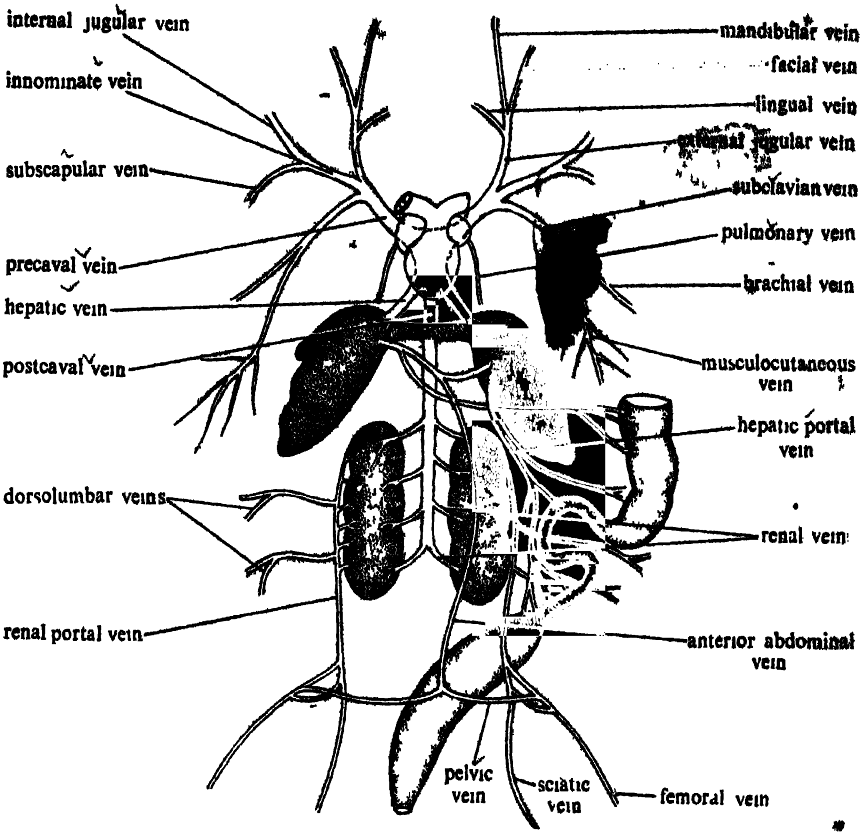

internal jugular vein
innominate vein
subscapular vein
precaval vein
hepatic vein
postcaval vein
dorsolumbar veins
renal portal vein
pelvic vein
sciatic vein
femoral vein
mandibular vein
facial vein
lingual vein
external jugular vein
subclavian vein
pulmonary vein
brachial vein
musculocutaneous vein
hepatic portal vein
renal vein
anterior abdominal vein

Fig 6 16 Venous system of *Bufo*

veins a *brachial vein* bringing blood from the forelimb and a *musculocutaneous vein* from the muscles and skin. As the skin acts as an accessory respiratory organ, the musculocutaneous vein brings the oxygenated blood. The post caval vein is formed by four or five pairs of *renal veins* which receive blood from the kidneys Blood from reproductive organs is also poured into renal veins by the *genital veins* The post caval vein then ascends to enter into the sinus venosus.

Portal veins. A portal vein has its origin in capillaries and it ends in capillaries The blood from the portal vein returns to heart through an intermediate organ The *hepatic* and *renal portal systems* are the two portal systems in toad. The capillaries from the gut unite to form a hepatic portal vein, which again breaks up into capillaries in liver. The capillaries from the posterior part of the body unite to form two renal portal veins which in turn break up into capillaries in the kidneys on their way to heart.

Hepatic portal system. This system comprises of *hepatic portal vein* and the *anterior abdominal vein* Hepatic portal vein carries blood from stomach, intestine, pancreas and spleen The main vessel receives the anterior abdominal vein under the liver and enters into the substance of the liver. The anterior abdominal vein is formed by the union of two *pelvic veins* in the midventral line. The pelvic vein arises as an offshoot of the *femoral vein*. On its anterior, the abdominal vein receives small branches from the urinary bladder and the ventral body wall.

Renal portal system. The blood from the hindlimbs is carried by the *femoral* and *sciatic veins*. Each femoral vein divides into two branches, a pelvic and the renal portal vein. The renal portal vein proceeds by the side of the corresponding kidney and enters into it to break up into the capillaries. Each renal portal vein receives two or three *dorsolumbar veins* carrying blood from the body wall.

LYMPHATIC SYSTEM

While circulating through the body, the blood does not come directly into the cells. During the transit of blood through capillaries, plasma exudes from the capillary wall into the intercellular spaces as the *lymph*. It is a colourless fluid with few leucocytes. The lymph from the intercellular spaces is collected by *lymphatic vessels* which in turn lead into *lymph sacs*. Some of the lymph vessels become contractile and are known as the *lymph hearts* which pump back the lymph into the veins. A pair of lymph-hearts opening into femoral vein is present near the urostyle and another pair is situated below the scapulae which open into subscapular veins.

NERVOUS SYSTEM

The nervous system of toad comprises of (1) the *central nervous system*, (2) the *peripheral nervous system* and (3) the *antonomous nervous system*. The nervous system controls and coordinates the various activities of the body.

CENTRAL NERVOUS SYSTEM

The central nervous system includes the brain and the spinal cord. It is essentially a hollow tube whose anterior portion becomes the brain and the posterior part narrows down to form the spinal cord. The cavity of the brain and the spinal cord is filled up with the *cerebrospinal fluid*. The brain and the spinal cord are made up of nerve cells (*neurones*) and nerve fibres. A collection of the extended processes of the neurones enclosed by a connective tissue sheath constitute the *nerves*.

Structure of a neurone. A neurone has a very large cell-body with a number of processes. The nucleus is very conspicuous and the cytoplasm contains numerous deeply stainable granules called the *Nissl's granules*. The processes are mostly branched, short and are called *dendrites*. One of the cell-processes is long and unbranched. It is known as *axon* which forms the *axis cylinder* of the nerve fibre. The solid part of the central nervous system is composed of *gray matter* and *white matter*. The aggregation of nerve cells with their nuclei give a grayish appearance and is recognised as the gray matter, while the collection of nerve fibres giving a white colour is known as the white matter. The relative arrangement of gray matter and white matter differs in different regions. In brain, the gray matter is situated on the outer side and the white matter lies towards the lumen. But the arrangement is just reverse in the spinal cord, i.e., the gray matter is situated on the inner side and the white matter on the outer side. The whole of the central nervous system is enclosed by two protective coverings or *meninges*. The outer one is the *duramater* which is thicker and fibrous in nature. The inner one is thin, highly vascular and called the *piamater*.

Development of the Central Nervous System. The nervous system develops from the embryonic ectoderm. Along the middorsal line of the whole length of the body above the notochord, the ectoderm forms a thickened *neural plate*. The sides of the neural plate rise up as lateral folds to form a *neural groove*. As development goes on, the edges of the groove fuse along the middorsal line and is converted into a *neural tube*. The anterior part is transformed into the brain and the posterior part forms the spinal cord. The brain was primarily a tube like structure, which due to unequal growth, torsions and bending transforms into a most complicated adult structure.

BRAIN

The brain is located inside the cranium. It is primarily differentiated into three parts by the development of two primary constrictions: the *forebrain* (or *prosencephalon*), the *midbrain* (or *mesencephalon*) and the *hindbrain* (or *rhombencephalon*). The prosencephalon constitutes the anteriormost part of the brain and becomes further subdivided into an anterior *telencephalon* and a posterior *diencephalon* (or *thalamencephalon*). The telencephalon gives off a pair of small olfactory lobes. These lobes are responsible for the sense of smell. The rest of the telencephalon comprises of two elongated ovoic lobes (Fig. 6.17A) called the *cerebrum* (or *cerebral hemispheres*). The roof of the cerebrum is very thin and the floor is very thick and called *corpus striatum*. The corpora striata are connected together by an *anterior commissure*. Above this commissure, there is an ill-developed *pallial commissure*. The cerebrum is the seat of consciousness, intelligence and it regulate voluntary motion. The surface of the cerebral hemispheres is smooth. The diencephalon is a very depressed part behind the cerebrum. It gives off dorsally a small projection, the *epiphysis*. Attached to the epiphysis, there is a small *pineal body* of unknown function. In front of the epiphysis there is a vascular membrane projecting into the lateral ventricle through the *foramen of Monro*. This projection is known as the *anterior choroid plexus*. The ventral side of the diencephalon bears an X-shaped *optic chiasma*. The optic chiasma is formed by the optic nerves (Fig. 6.17B). Just a little behind the optic chiasma hangs a projection, the *hypophysis* (or infundibulum). The pituitary gland is attached to the tip of the infundibulum. The lateral sides of the diencephalon become thick to form the *optic thalami*. The midbrain remains undivided and grows out dorsally as a pair of hollow ovoid bodies known as *corpora bigemina* (or *optic lobes*). Two longitudinal bands are present on the ventral side which connect the forebrain with the hindbrain. These are designated as the *crura cerebri*. The rhombencephalon is the posteriormost sector of the brain and becomes divided into *metencephalon* and *myelencephalon*. The metencephalon is represented by a thin transverse band-like *cerebellum*. The floor and the sides of the myelencephalon become very thick to form the *medulla oblongata*. The cerebellum co-ordinates the movement of the body. The medulla oblongata controls and regulates some of the vital processes, viz. the regulation of heart beat, metabolism and respiration. The roof of the myelencephalon is formed by a thin vascular membrane called the *posterior choroid plexus*.

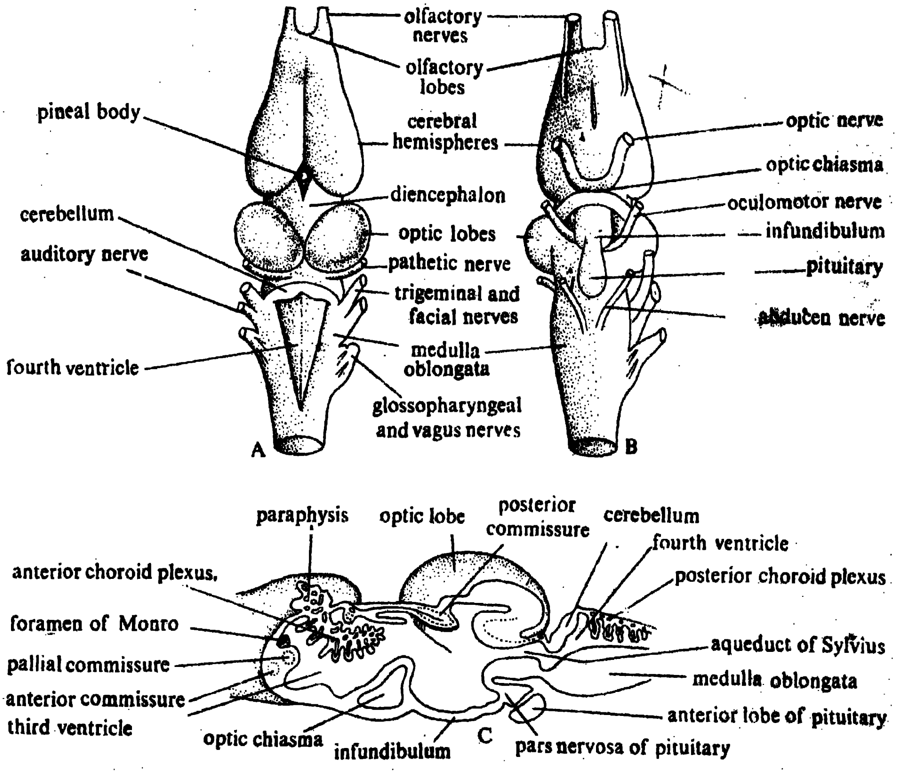

olfactory nerves
olfactory lobes
pineal body
cerebral hemispheres
diencephalon
cerebellum
optic lobes
auditory nerve
pathetic nerve
trigeminal and facial nerves
medulla oblongata
fourth ventricle
glossopharyngeal and vagus nerves
A
optic nerve
optic chiasma
oculomotor nerve
infundibulum
pituitary
abducen nerve
B
paraphysis
optic lobe
posterior commissure
cerebellum
fourth ventricle
posterior choroid plexus
anterior choroid plexus.
foramen of Monro
pallial commissure
anterior commissure
third ventricle
optic chiasma
infundibulum
C
aqueduct of Sylvius
medulla oblongata
anterior lobe of pituitary
pars nervosa of pituitary

Fig. 6.17. Brain of *Bufo*. A. Dorsal view. B. Ventral view. C. Diagrammatic longitudinal sectional view.

Cavities in brain. The brain is not a solid structure but contains well-formed internal cavities called *ventricles*. The cavities in the cerebral hemispheres constitute the *lateral ventricles* (or the *first* and the *second ventricles*). The cavity in the diencephalon constitutes the *third ventricle* and that of medulla oblongata is the *fourth ventricle*. The lateral ventricles remain in communication with the third ventricle by a small opening called the *foramen of Monro*. The third ventricle communicates with the fourth ventricle by a narrow passage (Fig. 6.17C) called the *aqueduct* of *Sylvius* (or *iter*). The fourth ventricle leads into the cavity of the spinal cord. The cavity in the optic lobes is known as *optocoel* and that in the olfactory lobes as the *rhinocoel*.

SPINAL CORD

The spinal cord is a hollow tube. It extends posteriorly from the medulla oblongata and remains encased within the neural canal of the vertebral column. It extends even within the urostyle as a slender filament, the *filum terminale*. The spinal cord has a middorsal groove called *dorsal fissure* and a similar *ventral fissure* is present on the midventral line (See Fig. 6.20). The cavity of the spinal cord is known as *neurocoel* which is also continuous with the ventricles of the brain.

PERIPHERAL NERVOUS SYSTEM

The peripheral nervous system comprises of the cranial and the spinal nerves arising from the cerebrospinal axis. A nerve is a bundle of nerve fibres, but in some cases, an aggregation of nerve cells causes swelling in the nerve. This swelling is called *ganglion*. The nerve fibres are of two types: (1) *Afferent or Sensory fibres*. These fibres convey the information from the receptor organs to the central nervous system and (2) *Efferent or Motor fibres*. These fibres carry impulses from the central nervous system to the effector organs. When the nerves are exclusively made up of sensory nerve fibres, these are called sensory nerves and those composed only of motor nerve fibres are known as motor nerves. Mixed nerves are also present which are composed of sensory as well as motor nerve fibres.

CRANIAL NERVES

Ten pairs of nerves originate from the brain. These paired nerves are designated as cranial nerves. Table Chordata-9 will give an idea about the origin and distribution of the cranial nerves in toad.

TABLE CHORDATA–9

Serial Number	Name	Nature	Origin	Distribution
I.	Olfactory nerve.	Sensory.	Olfactory lobes.	Gives branches to the mucous membrane of the nose.
II.	Optic nerve.	Sensory.	Optic lobes.	Gives nerves to the retinal layer of the eye. Two optic nerves cross each other and form X-shaped optic chiasma.
III.	Oculomotor nerve.	Motor.	The ventral side of the mesencephalon.	Supplies nerves to the extrinsic muscles of the eyes.
IV.	Trochlear or Pathetic nerve.	Motor.	The dorsal surface of mesencephalon behind the optic lobes.	Innervates the superior oblique muscle of the eye ball.
V.	Trigeminal nerve.	Mixed.	The lateral side of the medulla oblongata.	After its origin, it gives off a *gasserian* (or *prootic*) *ganglion*. It then comes out of the skull and becomes divided into three branches (Fig. 6.18): (*i*) *Ophthalmic branch* sends sensory nerve fibres to the upper eyelid, anterior part of head and mucous membrane of the nose. (*ii*) *Maxillary branch* gives sensory nerve fibres to the upper lip, mucous membrane of the upper jaw and the lower eyelid.

				(*iii*) ***Mandibular branch*** is a mixed type of nerve, because it sends motor nerve fibres to the floor of the buccal cavity and sensory fibres to the skin of the buccal cavity.
VI.	Abducens nerve.	Motor.	The ventral side of the medulla oblongata.	It supplies the external rectus muscle of the eye.
VII.	Facial nerve.	Mixed.	The medulla oblongata just behind the fifth cranial nerve.	It runs into the gasserian ganglion and leaves the cranium as a separate nerve along with the trigeminal and divides into (Fig. 6.18): (*i*) ***Palatine branch*** which gives nerves to the roof of mouth. (*ii*) ***Hyomandibular branch*** which receives a branch from the glossopharyngeal and supplies nerve to tympanum, mandibular joint and the floor of the buccal cavity.
VIII.	Auditory nerve.	Sensory.	Lateral side of the medulla oblongata.	It gives nerve to the internal ear.
IX.	Glossopharyngeal nerve.	Mixed.	The lateral side of the medulla oblongata.	Immediately after origin it runs into the vagus ganglion and is separated from it as an independent nerve. It is also joined with the hyomandibular branch of the facial nerve. It innervates the floor of the buccal cavity and tongue.
X.	Vagus or Pneumogastric nerve.	Mixed.	The medulla oblongata by many roots.	After its origin, the vagus nerve bears a ***vagus ganglion***. It then comes out of the cranium through an aperture in the exoccipital bone. It gives of four main branches (Fig 6.19): (*i*) ***Laryngeal nerve*** to the laryngotracheal chamber, (*ii*) ***Cardiac nerve*** to the heart (*iii*) ***Pulmonary nerve*** to the lun and (*iv*) ***Gastric nerve*** to the alimentary canal. Of all the cranial nerves, th vagus nerve is the most vita one, because it controls hear beat, peristalsis of the digestive tract and the respirator movements.

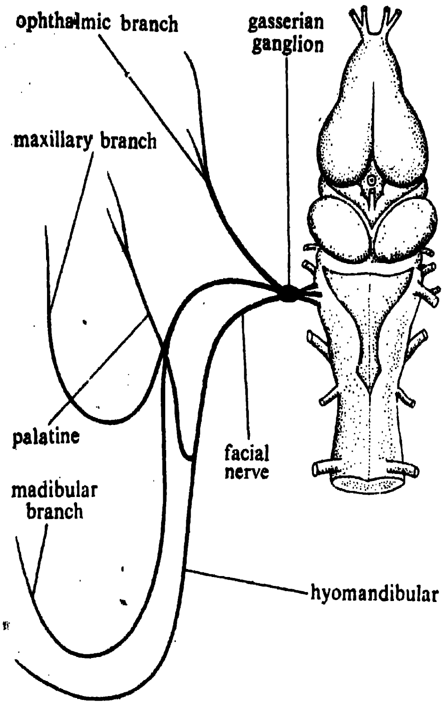

ophthalmic branch
gasserian ganglion
maxillary branch
palatine
facial nerve
madibular branch
hyomandibular

Fig. 6.18. Showing the origin and distribution of the fifth and seventh cranial nerves in *Bufo*.

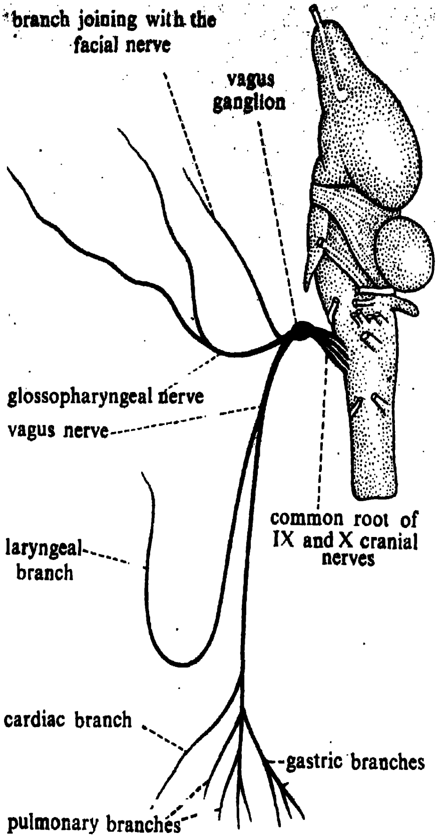

branch joining with the facial nerve
vagus ganglion
glossopharyngeal nerve
vagus nerve
common root of IX and X cranial nerves
laryngeal branch
cardiac branch
gastric branches
pulmonary branches

Fig. 6.19. Showing the origin and distribution of the ninth and tenth cranial nerves in *Bufo*.

SPINAL NERVES

There are ten pairs of spinal nerves in toad. All the spinal nerves are of mixed nature. Each spinal nerve has a *dorsal sensory root* and a *ventral motor root*. The dorsal root possesses a ganglion near its origin. The dorsal and ventral roots unite and form a common trunk which comes out through intervertebral foramen and gives off three branches (Fig. 6.20): (1) a large *ventral branch* which innervates the skin and muscles on the ventral surface of the body, (2) a small *dorsal branch* which supplies the skin and muscles on the dorsal side of the body and (3) a very small *ramus communicans* which joins with the nearest sympathetic ganglion. The first spinal nerve is known as *hypoglossal*. It supplies the muscles of the tongue. The second and third spinal nerves form the *brachial plexus*. The fourth, fifth and sixth spinal nerves supply the integument and the muscles of the trunk region. The rest of the spinal nerves form the *sciatic plexus* which gives origin to the large sciatic nerve to supply the hindlimb. The last spinal nerve is insignificant.

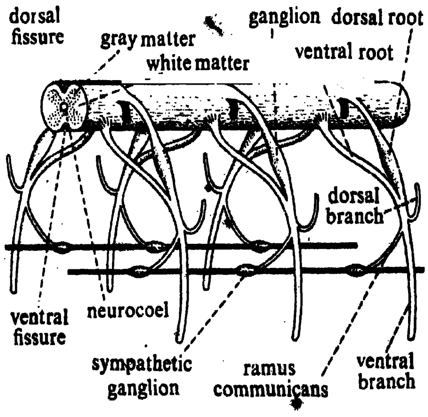

dorsal fissure
gray matter
white matter
ganglion
dorsal root
ventral root
dorsal branch
ventral fissure
neurocoel
sympathetic ganglion
ramus communicans
ventral branch

Fig. 6.20. Showing the origin of the spinal nerves from the spinal cord and their relation with sympathetic nervous system in *Bufo*.

AUTONOMIC NERVOUS SYSTEM

The autonomic nervous system consists of two sympathetic trunks one on either side of the dorsal aorta. The sympathetic trunks start near the point of formation of iliac arteries and each trunk contains ten small ganglia connecting with the corresponding spinal nerve by ramus communicans. Anteriorly, the sympathetic trunk divides to encircle the subclavian artery. It then enters into the cranium, connected by a twig with the vagus ganglion and terminates after connecting with the gasserian ganglion. The sympathetic trunks give out branches to innervate the cardiac muscles, blood vessels and alimentary canal. These branches may sometimes unite to form ganglionated plexuses, such as the *cardiac plexus* and *solar plexus*. The autonomic nervous system regulates the involuntary activities of the body like heart beats and peristalsis of the alimentary canal. It is an autonomic nervous system in the sense that its activities are somewhat independent of the central nervous system.

SENSE ORGANS

The sense organs are the receptors for external stimuli. These are the avenues through which the central nervous system is kept informed of the outside world. Each receptor organ can respond to a particular type of stimulus and produces its own specific sensation. Receptors for cold, heat, pain and touch are present beneath the epidermis of the skin. These are microscopic in structure and are usually regarded as *cutaneous receptors*.

Receptors for smell. These receptors are scattered in the nasal passage. The mucous membrane lining the nasal passage contains peculiar olfactory cells and slender supporting cells. The olfactory cells are connected with nerve fibres from the olfactory nerve and are the actual receptors of smell.

Receptors for taste. The taste buds present in the tongue and mouth cavity are the receptors for the taste. Each taste bud is made up of two types of cells, the *taste cells* and the *supporting cells*. The taste cells are connected with the nerve fibres from the glossopharyngeal nerve. Taste buds are located in the tongue in association with minute elevations called the *papillae*.

Receptors for vision. The eyes are the two very compact photosensitive organs. These organs are lodged in the orbits. Each eye has a spherical body and is usually called the eye-ball. The eye-ball can be rotated inside the orbit within its limit by six extrinsic muscles. These muscles are: (1) *Superior rectus*, (2) *inferior rectus*, (3) *external rectus*, (4) *internal rectus*, (5) *superior oblique* and (6) *inferior oblique*. The eye can be protruded by the *levator bulbi* and can be withdrawn by the *retractor bulbi* to a certain limit. The eye-ball is composed of three layers arranged in a regular sequence (Fig. 6.21A). These are: (A) *Sclerotic layer*. This is the outermost layer of the eye-ball. It is very tough and thick. It consists of two parts: An anterior transparent circular portion called the *cornea* and an opaque posterior portion called the white of the eye-ball. The cornea permits the entry of light rays inside the eye. The outer surface of the cornea is covered by a thin transparent membrane called the *conjunctiva*. The sclera is composed of cartilage and fibrous tissue and gives protection to the delicate parts of the eye. (B) *Uvea* or the middle layer. This layer is divided into three parts: (*a*) the *choroid*, (*b*) *iris* and (*c*) *suspensory ligament*. The choroid part is a highly vascular pigmented layer. At the anterior end and just behind the cornea, the choroid is modified to form a circular pigmented disc called the *iris*. The iris contains an aperture at the centre which is known as the *pupil*. The iris acts as a diaphragm and contains circular and radial muscle fibres which help the pupil to contract or dilate. Excepting the pupil, the eye-ball is totally light-proof. The iris regulates the entry of light into the eye-ball. Just behind the iris, there are suspensory ligaments which keep the lens in position. (C) *Retinal layer*. The retinal layer forms the innermost and the lightsensitive screen of the eye. It contains two types of photosensitive cells called the *rods* and the *cones*. The cones are primarily concerned with the colour vision in bright light and the rods are chiefly useful in colourless vision at low light intensities. Photosensitive cells are connected with the nerve fibres of the optic nerve.

A crystalline lens is situated just behind the pupil and is kept in position by suspensory ligament. The lens divides the cavity of the eye into two chambers. The anterior chamber between the lens and the cornea is filled up with a watery fluid, the *aqueous humor* and the posterior one behind the lens is filled up with a transparent jelly-like substance, the *vitreous humor*. Just at the point of entry of the optic nerve into the retinal layer there is a depression known as *blind spot* where no image is formed. Two muscles, one dorsal and the other ventral, are connected with the suspensory ligament of the lens and with the cornea. These muscles are known as the *protractor lentis*. Contraction of the protractor lentis draws the lens closer to the cornea and when relaxed the lens is pushed away from the cornea.

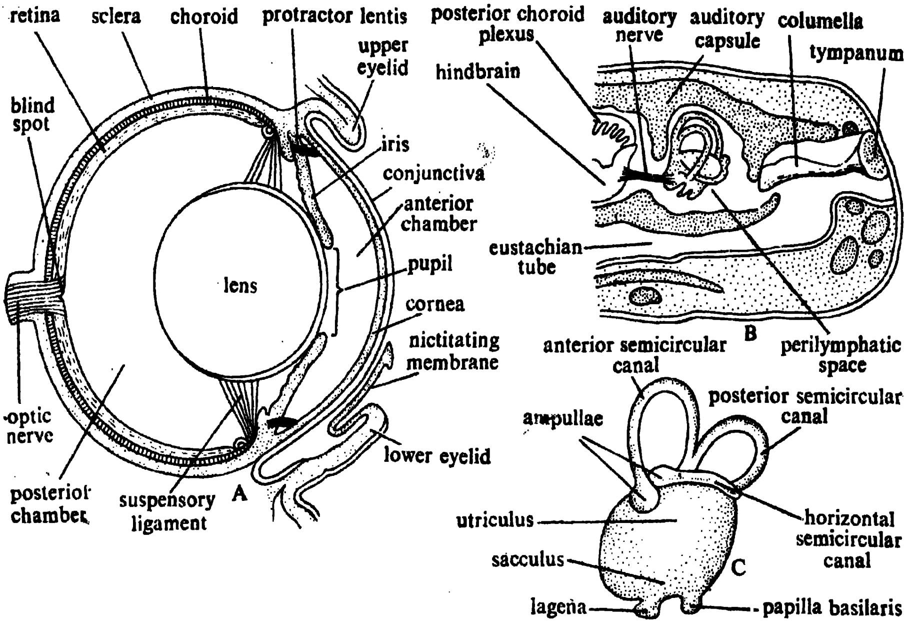

retina
sclera
choroid
protractor lentis
upper eyelid
blind spot
iris
conjunctiva
anterior chamber
lens
pupil
cornea
nictitating membrane
optic nerve
lower eyelid
posterior chamber
suspensory ligament
A
posterior choroid plexus
hindbrain
auditory nerve
auditory capsule
columella
tympanum
eustachian tube
anterior semicircular canal
B
perilymphatic space
posterior semicircular canal
ampullae
utriculus
sacculus
lagena
C
horizontal semicircular canal
papilla basilaris

Fig. 6.21. Sense organs of *Bufo*. A. Diagrammatic vertical section of an eye. B. Partial sectional view of the head region passing through the ear. C. A membranous labyrinth.

Mechanism of vision. Light rays, on the way through cornea, pupil and the lens, are converged to the retinal layer. In the retinal layer an inverted and reduced image is formed which is transmitted to the brain *via* the optic nerves. This inverted image is translated into a corrected one by the brain. Adjustment of the image (*accommodation*) on the retinal layer is done by the forward and backward movement of the lens by the protractor lentis.

The photochemical basis of image formation relates that the vision depends upon the photosensitive pigments present in the photosensitive cells. Visual purple (*rhodopsin*) is abundant in the rods and visual violet (*iodopsin*) is present in the cones. The synthesis of both these pigments depend upon the presence of Vitamin A. The pigments are decomposed by the light and various products are produced which can create impulses in the photoreceptor cells of the retina.

Two types of vision are encountered in animals, one is the *binocular vision* which means that the two eyes can be focussed on the same object and the other is the *monocular vision* when each eye has a different visual field. In toad the vision is monocular, because eyes are laterally placed and cover different visual areas.

Receptors for hearing and balancing. The ears subserve dual functions, hearing and balancing. The ear of toad consists of three parts: the *external ear*, the *middle ear* and the *internal ear*. The external ear is represented by a tightly stretched membrane called the *tympanum*. The middle ear is a tube-like cavity. The cavity of the middle ear is in communication with the buccal cavity by *eustachian tube*. Presence of the eustachian tube equalises the atmospheric pressure on the two sides of the tympanum. A bony rod, the *columella* connects the tympanum with the membranous partition separating the middle and the internal ear. The internal ear is represented by the *membranous labyrinth* which is enclosed by the auditory capsule (Fig. 6.21B). The membranous labyrinth floats in a fluid known as *perilymph* and the cavity of the labyrinth is filled with another fluid known as *endolymph*. The auditory capsule is sealed from all sides by a membranous partition. Membranous labyrinth is made up of two chambers. The upper chamber is called the *utriculus* and the lower one is the *sacculus*. The utriculus gives out narrow tubular *semicircular canals* (Fig. 6.21C). There are three semicircular canals, one is horizontal in position and the other two are vertically disposed. All the three semicircular canals are arranged at right angles with one another. Both the ends of the semicircular canals open into the utriculus. Each canal bears an *ampulla* at its one end only. The sacculus produces a short projection called *lagena*. Patches of sensory receptors are present in the inner wall of the membranous labyrinth. Each patch is composed of sensory cells and supporting cells. Receptor cells are connected with the nerve fibres from the auditory nerve.

Mechanism of hearing. Sound waves directly impringe upon the tympanum and the vibrations are conveyed by the columella to the perilymph. From the perilymph, the vibrations are carried to the endolymph and thus stimulate the sensory cells of the sacculus and lagena. The impulses are transmitted to the brain through the auditory nerves and are perceived as sound in the brain.

Mechanism of balancing. The semicircular canals maintain the equilibrium of the body. Calcareous particles (*otoliths*) present inside the semicircular canals strike upon the bristles of receptors as the animals lose the balance. Besides, the semicircular canals are arranged in such a fashion, that these can easily detect changes of the center of gravity during movement.

ENDOCRINE SYSTEM

The endocrine system includes many ductless glands which secrete the hormones directly into the blood stream. The endocrine glands of toad are as follows: (1) *Pituitary gland.* This gland has two lobes, an anterior lobe and a posterior lobe. The anterior lobe of the pituitary gland secretes a growth-stimulating hormone, a thyroid stimulating hormone, a gonad-stimulating hormone and many other hormones for the regulation of the activities of the other endocrine glands. (2) *Thyroid glands.* There is a pair of small oval thyroid glands situated on the floor of the buccal cavity one on each side of the hyoid apparatus. The thyroid glands produce a hormone called thyroxine. (3) *Parathyroid glands.* These are oval yellowish glands situated near the thyroid glands. (4) *Thymus glands.* These are small yellowish bodies situated on either side behind the tympanum. (5) *Adrenal glands.* These glands are represented by narrow orange coloured bands situated on the ventral side of the kidneys. The cortex produces a hormone called cortin and the medulla secretes the adrenalin. (6) *Pancreas.* This gland contains two types of glandular structures. The exocrine part secretes pancreatic enzymes while the endocrine part (islets of Langerhans) produces insulin. (7) *Gonads.* Besides the production of germ cells, the gonads produce sex hormones.

URINOGENITAL SYSTEM

Although excretory system and the reproductive system are functionally different, it is a general practice to describe these two systems under a common topic —the urinogenital system.

Excretory system

During metabolism various nitrogenous waste products are formed in the body. These waste products should be eliminated. Because these are not only useless but detrimental to the body if retained inside. The process concerning the extraction of nitrogenous waste products and their removal from the body is called the excretion. Nitrogenous waste products such as urea, uric acid and excess of water with some salts are excreted as the urine. The organs responsible for this phenomenon are: (1) a pair of kidneys, (2) a pair of ureters, (3) an urinary bladder, (4) the cloaca and (5) the vent.

Kidneys. The kidneys are two in number. Each kidney has a compact elongated structure and attached to the dorsal side of the body wall. These are retroperitoneal in position, i.e., not enclosed within the peritoneum. The kidneys are of mesonephric type. The edges of the kidneys are marked by notches (Fig. 6.22). Each kidney is composed of innumerable microscopic *uriniferous tubules* (or *nephrons*). Each uriniferous tubule has a proximal two-walled cup-like structure known as the *Bowman's capsule*. A small afferent vessel from the renal artery enters into the capsule and breaks up into a network of capillaries to form the *glomerulus*. From the glomerulus an efferent vessel emerges out and pours the blood into the renal vein. The Bowman's capsule together with the glomerulus constitutes the *Malpighian body* (or *renal corpuscle*). The other end of the Bowman's capsule is communicated with the coiled tubule. This convoluted part of the tubule is supplied by capillaries from renal portal vein. These tubules open into the *collecting tubules* which in turn open into the ureter. Numerous minute openings called *nephrostomes* are present on the ventral side of the kidneys. The ureters unite posteriorly to form a common duct which opens into the cloaca. Opening into the ventral side of the cloaca there is a bilobed urinary bladder. The bilobed urinary bladder is formed by the fusion of two urinary bladders.

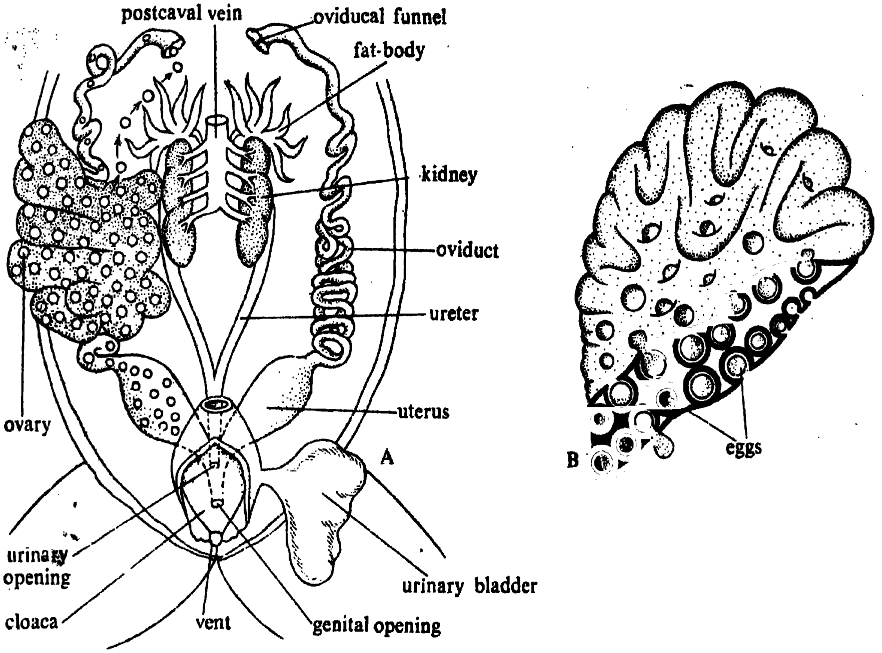


Fig. 6.22. A. Excretory and genital system of a female *Bufo*. The arrows indicate the path of transportation of the egg from the ovary into the oviducal funnel. Ovary of one side has been shown. B. An enlarged sectional view of ovary showing the discharge of eggs.

Physiology of urine formation. The blood, containing excretory products is brought to the kidney by renal artery and the renal portal vein. On its way through glomerulus, water containing nitrogenous waste products and other substances is filtered out into the capsular space. The filtrate then passes through the convoluted tubule where the useful substances are reabsorbed and go back into the circulating blood. The fluid from the tubules is collected by the collecting tubules and drains into ureters as the urine. Urine then drips into the cloaca and is stored temporarily in the urinary bladder. When fully filled with urine, the urinary bladder contracts to eject the urine through vent. With all probabilities, the nephrostomes drain away excess of water and wastes from the body cavity.

Reproductive system

The sexes are separate. Sexual dimorphism is present in toad. During breeding season, a cushion-like thumb pad appears at the base of each innermost finger of male. Male is provided with a vocal sac opening into the buccal cavity. During breeding season females have distended abdomen to accommodate the eggs. In both the sexes, several yellowish outgrowths called fat bodies are present anterior to the gonads. The fat bodies are the store house of fatty substances which are utilised during hibernation and also during germ cell formation.

Female Reproductive System. The female reproductive system consists of two *ovaries* and two *oviducts*. Each ovary is an irregular much folded sac and is attached with the ventral side of the kidney by *mesovarium*. During breeding season, the ovaries become greatly enlarged. The female *gonoduct* (or *oviduct*) is a very long coiled tube and is placed on the lateral side of the body. Each oviduct is differentiated into three parts (Fig. 6.22A). Anteriorly, the oviduct opens directly into coelom by a funnel-like opening called *oviducal funnel*. So oviduct has got no direct connection with the ovary. The median portion is extensively coiled and glandular. The posterior part becomes dilated to act a thin-walled *uterus* (or *ovisac*). The two uteri unite to form a common median tube which in turn opens to the dorsal side of the cloacal chamber. The eggs, after maturation, are discharged into the body cavity by rapture of the ovarian wall (Fig. 6.22B) and then find their passage into the oviduct through the opening of the oviducal funnel.

Male Reproductive System. The male reproductive system comprises of two elongated white bodies called the *testes* (Fig. 6.23A). Each testis is attached with the ventral side of the kidney by the *mesorchium*. Each testis is made up of a collection of fine seminiferous tubules which manufacture *spermatozoa* or male germ cells. The seminiferous tubules are connected with the collecting tubules of kidney by fine ducts called the *vasa efferentia*. The vasa efferentia open into the ureter, which in male, is known as the *urinogenital duct*. Through the urinogenital duct, both the male gametes and urine are poured into the cloaca (Fig. 6.23B). Just in front of the testis and attached to the anterior end of each kidney, there is a small rounded body called *Bidder's organ*. It is regarded as an undeveloped ovary and may be functional if the testes are removed. This peculiar structure is also present in female in an ill-developed condition. This organ is regarded by some as an *ovotestis*.

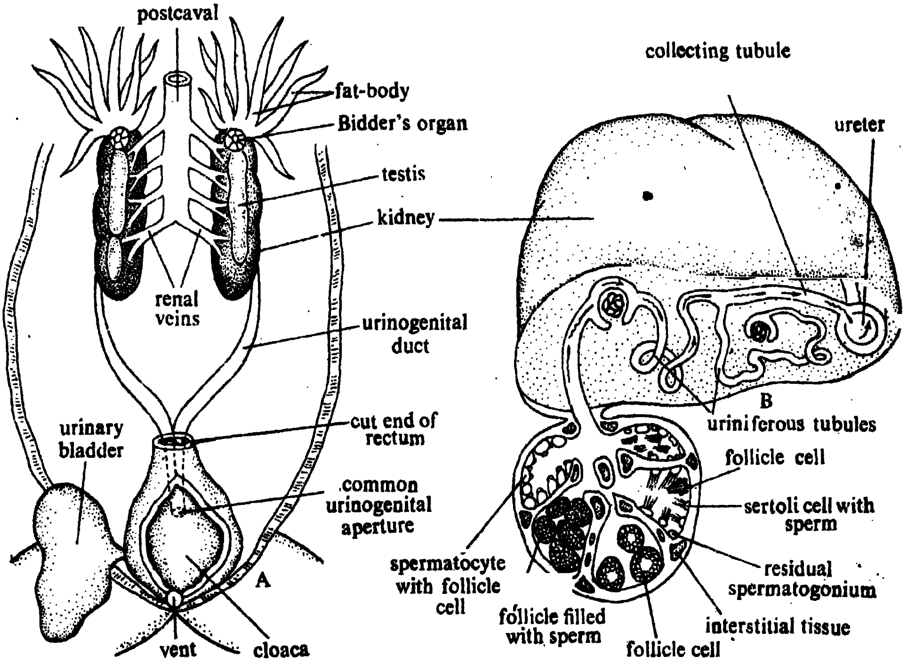

postcaval
fat-body
Bidder's organ
testis
kidney
renal veins
urinogenital duct
urinary bladder
cut end of rectum
common urinogenital aperture
A
vent
cloaca
collecting tubule
ureter
B
uriniferous tubules
follicle cell
sertoli cell with sperm
residual spermatogonium
spermatocyte with follicle cell
follicle filled with sperm
interstitial tissue
follicle cell

Fig. 6.23. A. Urinogenital system of a male *Bufo*. B. Diagrammatic section of the kidney and testis. Note the relationship of the sperm duct with the urinary tubule.

LIFE-HISTORY

The life-history of toad is very much complicated. Toad breeds during rainy season.

Structure of germ cells. The eggs are spherical cells. Each egg has a blackish animal pole and a whitish vegetal pole. The animal pole is full of protoplasm and the vegetal pole is full of yolk. Such a type of egg is called the *telolecithal* type. Each egg is surrounded by *vitelline membrane.* The egg gets a coating of jelly-like albumen while passing through the convoluted part of the oviduct. The spermatozoa are highly specialised cells with an oval head containing nucleus, a short neck having centrosome and a long wavy protoplasmic tail.

Fertilization. Union of male and female gametes takes place externally, i.e., fertilization is external. The outer membrane of the egg gives an impass to one sperm after which the outer membrane becomes impervious to other sperms. Only the head portion of the spermatozoa enters into the cell-body of ovum and the tail is left out. The sperm nucleus is called *male pronucleus* and the egg nucleus is known as *female pronucleus.* During fertilization, the male and female pronuclei fuse to form a single nucleus. The egg, thus fertilized is known as the *Zygote.*

Embryonic development. The zygote undergoes rapid divisions known as *cleavage* (or *segmentation*) and results in the production of a large number of blastomeres (Fig. 6.24). The cells now arrange to form a cellular ball known as *blastula.* Now the blastula enters into a complicated stage known as the *gastrula* and the process is known as gastrulation. The gastrulation is essentially a process of cell movement when the different cells take up their respective position for future differentiation. During this process three primary germinal layers, (1) ectoderm, (2) mesoderm and (3) endoderm are differentiated. All the structures of the adult are developed out of these three primary germinal layers. After about two weeks a small embryo is seen moving within the egg. The developing embryo gets nourishment from the yolk and eventually hatched as the tadpole larva. Fig. 6.25 illustrates the larval development and metamorphosis of toad.

Structure of a freshly hatched tadpole larva. A freshly hatched tadpole larva has a limbless body. The body is divided into an ovoid head, a short trunk and a slender tail. A small opening situated ventrally at the root of the tail is known as the anus. An adhesive *sucker* is present on the ventral side of the head by which the tadpole larva attaches itself to the aquatic weeds. The mouth is lacking and as a result it cannot take anything from outside. The yolk material provides the nutrition. The respiratory organs comprise of three pairs of highly vascular and branched

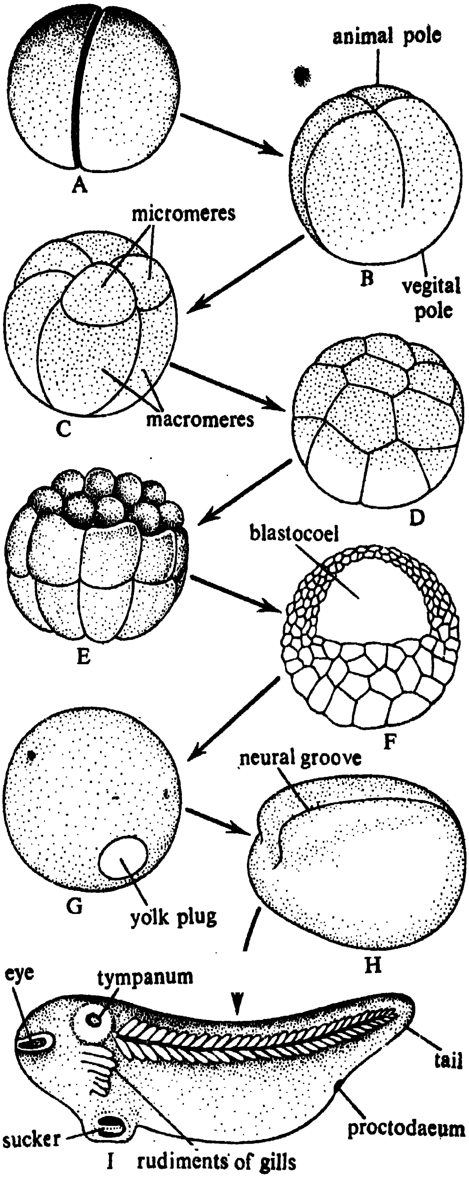


Fig. 6.24. Pre-larval developmental events in *Bufo*. F. Sectional view.

feathery *external gills*. After a few days the mouth is formed near the sucker. A pair of horny jaws surrounds the mouth. The tail becomes more elongated and develops a dorsal and a ventral fin. V-shaped myotomes develop on both the sides of the tail.

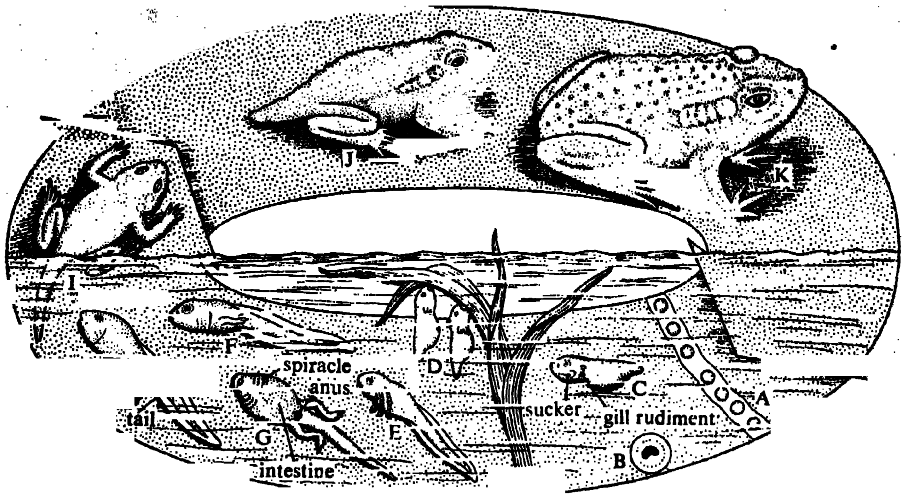


Fig. 6.25. Schematic representation of the larval development and metamorphosis of *B* Note that the early phase is passed in water (A–I). J. A freshly metamorphosed *Bufo*. K. An adult *B*

At this time this free swimming tadpole larva ingests water weeds, as result of which, the alimentary canal becomes extremely elongated. To accommodate such a long alimentary canal inside the cavity of a short trunk, it becomes spirally coiled like the spring of a watch.

Structure of an advanced tadpole larva. In the advanced stage, the pharynx of the tadpole larva becomes perforated by gill-slits. External gills disappear and the *internal gills* are formed between the gill-slits. The gills and the gill-slits are covered by the *operculum* (or *gill-cover*). The operculum fuses with the trunk on all sides except a small opening called the *spiracle* on the left side. Water enters into the pharynx through the mouth and goes out through the spiracle. During this transit of water the internal gills are bathed with water containing oxygen dissolved in it. While the internal gills are functioning, a pair of lungs develops as outgrowths from the pharynx on the ventral surface. The hindlimbs appear prior to the forelimbs. The forelimbs remain first hidden under the operculum and subsequently emerge through it. At this stage both the internal gills as well as the newly formed lungs are functional. When the lungs become fully developed, the internal gills become degenerated. At this stage it looks like a miniature toad except having a tail. As the limbs are developing, the animal enters into a period of starvation. The material of the tail becomes eventually absorbed into the body.

Structure of a freshly formed toad. After the absorption of tail, the young toad leaves the primal aquatic home and comes to the land and hops. The mouth becomes wider and a pair of true bony jaws replaces the horny jaws. It now changes its food habit to carnivorous type, as a result the alimentary canal becomes short and less coiled.

Metamorphosis. The phenomenon of metamorphosis is well illustrated in the life-history of toad. The young tadpole larva resembles a fish. It leads an independent and self-supporting life. This fish-like tadpole larva completely metamorphoses into a toad. The metamorphosis of toad is exclusively a progressive process and is controlled by the thyroid glands. Removal of thyroid glands in the tadpole larva retards metamorphosis. Anterior pituitary indirectly plays an important role during metamorphosis by stimulating and controlling the function of the thyroid glands.

SOME INTERESTING AMPHIBIANS

The amphibians are adapted to different modes of living. Some of them are fully terrestrial as adults while others are either arboreal or lead subterranean life and the rest live in the primal watery home. As a consequence a large variety of forms is encountered.

NECTURUS. *Necturus* is a modified urodele with persistent external gills (Fig. 6.26H) and lateral line sense organs. It is commonly called the North American Water-newt or Mud-puppy. It attains the

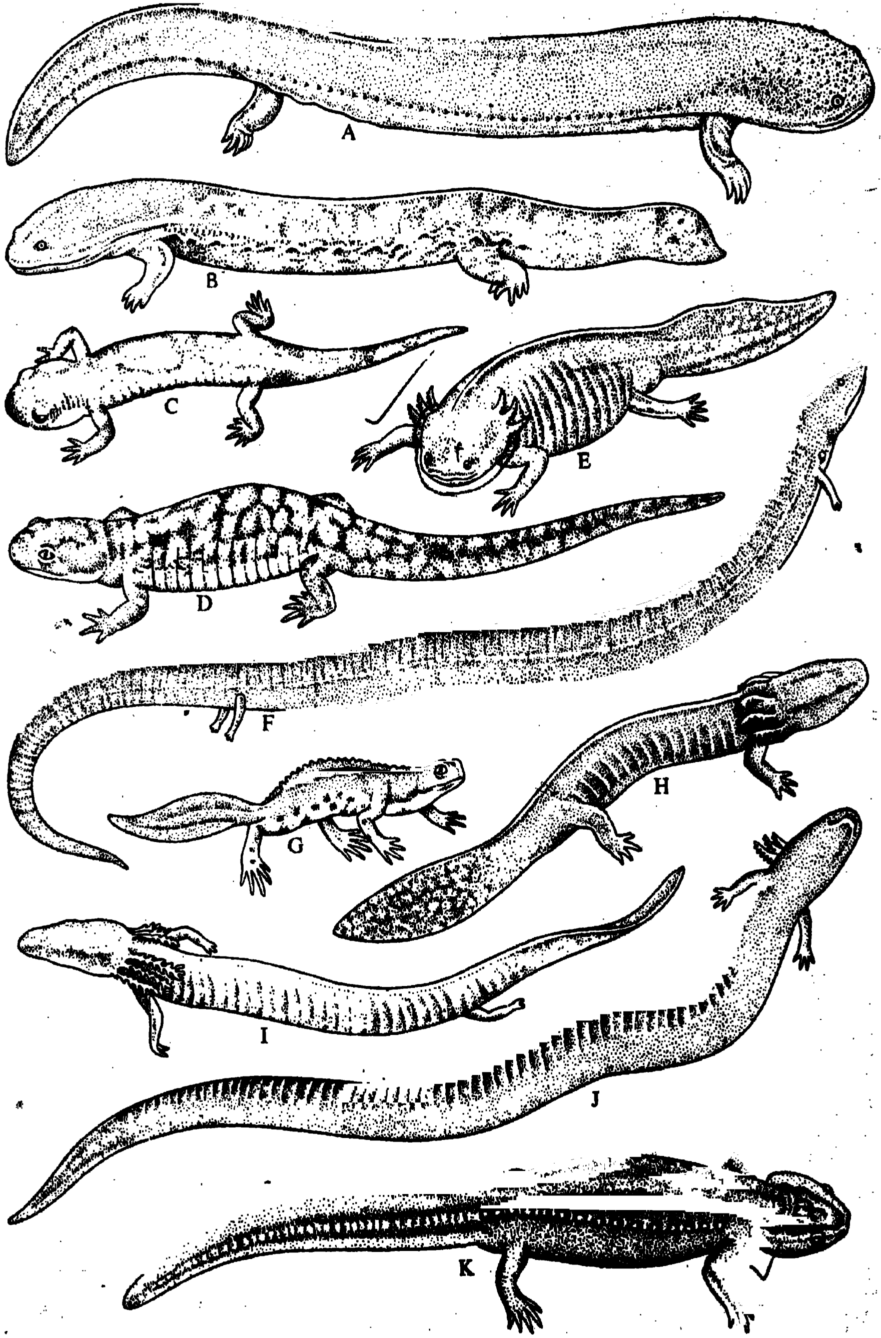


Fig. 6.26. Some important urodeles. A. *Megalobatrachus*. B. *Cryptobranchus*. C. *Salamandra*. D. Adult *Ambystoma*. E. *Axolotl* larva of Ambystoma. Note the presence of continuous dorsal and caudal fin. F. *Amphiuma*. G. *Triturus*. H. *Necturus*. I. *Proteus*. J. *Siren*. K. *Tylototriton*.

length of about 35 cm. The trunk is elongated and the tail is laterally compressed with continuous median fin. The limbs are small and feebly developed. There are four digits in each limb. The eyes are small with no eyelids. Two gill-slits are present. The lungs are greatly reduced. The eggs are laid under submerged stones and are guarded by the females.

PROTEUS. *Proteus* (Fig. 6.26I) is a blind urodele inhabiting the European caves. It resembles Necturus in many respects. The limbs are ill-developed. The forelimbs are provided with two fingers and the hindlimbs bear two toes. There are external gills like that of Necturus. The body is colourless.

SIREN. *Siren* (Fig. 6.26J) has almost the same morphological construction as the Necturus. It retains almost entirely the larval characteristics. Siren has an elongated eel-like body without any external trace of hindlimbs. The pterygoids are greatly reduced. The coracoid exists as a separate ossified piece. A prominent *vomeronasal organ* (or *organ of Jacobson*) is present.

AMPHIUMA. *Amphiuma* (Fig. 6.26F) has an eel-like body and is usually called the 'Conger-eel'. It is found mostly in North America and also in the southern part of America. It is a semilarval creature with lungs and absurdly small legs with two or three digits. The eyes are devoid of eyelids. There are four branchial arches. The skull contains a bony pterygoid, prevomeral processes and premaxillary spines separating the nasals. There is no trace of external gills in adult, but two pairs of gill-slits are retained throughout life.

AMBYSTOMA. *Ambystoma* (or *Amblystoma*) is a North American terrestrial newt (Fig. 6.26D). It has almost the same organisation as that of *Amphiuma*. The limbs are moderately developed with four digits in the forelimbs and five digits in the hindlimbs. A series of palatal teeth is present. *Ambystoma mexicanum* becomes mature without metamorphosis because of the absence of iodine in water.

AXOLOTL LARVA. Larvae of two genera of urodeles, *Ambystoma* and *Triton* have the power of developing the sex organs and thus are able to reproduce at the premature stage. This phenomenon of attainment of sexual maturity in larval phase is called the *neoteny* (or *paedogenesis*). Such neotenous larval phase is called the Axolotl larva (Fig. 6.26E). The Axolotl larva of Ambystoma has a well-developed post anal tail with a continuous tail fin unsupported by fin-rays. It has three pairs of external gills and four pairs of gill-slits. The cause of retention of larval characters and the absence of metamorphosis from aquatic to land life, appears to be due to abundance of food, lack of iodine in water and other favourable conditions of life. The axolotl becomes sexually mature at the age of about six months. It breeds several times a year. The axolotl is found in that stage in different parts of United States.

The axolotl is known since long time. It was regarded first to be related to a perenibranchiate form, specially to Siren and gets the name *Siredon axolotl* or *Siredon pisciformis*. But in 1865 some such specimens were transported from the United States to France where they started to breed and finally underwent metamorphosis. They lost the gills and other larval features and transformed into adult Ambystomas. Since then, the Axolotls are identified as the sexually mature larvae of Ambystoma.

TRITON. *Triton* is an aquatic European newt with laterally compressed tail. The limbs are moderately developed with four digits in the forelimbs and five digits in the hindlimbs. The eyes are provided with eyelids. The palatine teeth are present in two longitudinal rows. The parasphenoid is toothless. The vertebrae are opisthocoelous. They are oviparous and the eggs are glued singly to aquatic weeds or submerged stones. The larvae may attain sexual maturity and fail to undergo metamorphosis.

SALAMANDRA. *Salamandra* (Fig. 6.26C) is the European land salamander with a subcylindrical tail. There is no trace of either gill or gill-slit in adult. The branchial arches are greatly reduced. Two pairs of limbs are present. The forelimbs are provided with four digits and the hindlimbs are with five digits. The vertebrae are opisthocoelous. The vomerine teeth are present on either side of the parasphenoid. *Salamandra maculosa* (spotted salamander) is viviparous and youngs emerge as the larvae. The skin contains poisonous glands which eject white poisonous fluid. *Salamandra atra* is also a viviparous form and produces two youngs at a time. While intrauterine, the youngs develop external gills which absorb oxygen and nutrition.

TRITURUS. *Triturus* (Fig. 6.26G) is a common British newt which, like that of Salamandra, lacks any trace of gills or gill-slits. The branchial arches are reduced. The limbs support much of the weight of the body and are plantigrade. There is a serrated middorsal crest on the back. The tail is cylindrical in nonbreeding season, but in breeding season it, specially in males, develops a large fin.

TYLOTOTRITON. *Tylototriton* (Fig. 6.26K) is the only Indian urodele found in the eastern Himalayan region. It resembles Salamandra very closely. It attains a length of about 15–20 cm. The head bears two ridges on the dorsolateral sides. The back of the the body bears a median vertebral ridge and two beaded lines laterally placed. The tail is laterally compressed.

MEGALOBATRACHUS. *Megalobatrachus* (Fig. 6.26A) is a giant salamander of China and Japan. It attains a length of about 1.65 m. All traces of gills or gill-slits disappear, but two branchial arches persist. The eyes are devoid of eyelids. The limbs are functional with four digits in the forelimbs and five digits in the hindlimbs.

CRYPTOBRANCHUS. *Cryptobranchus* (Fig. 6.26B) is called the 'hell bender' of the United States. There is a single branchial aperture (spiracle) on the left side only and is used for the outlet of water during respiration. Four branchial arches are present. Like that of Megalobatrachus, the limbs are functional. The eyes are lidless. The skin on the dorsolateral sides of the body shows flabby folds.

RANA. *Rana* is one of the most common examples of the frogs (Fig. 6.27A). It has almost similar anatomical organisation as that of *Bufo*. The outline of the head is triangular and the teeth are present only on the upper jaw. The vomers are provided with teeth. The fingers are free, but the toes are webbed. The eighth vertebra is amphicoelous and the transverse processes of the ninth vertebra are cylindrical. There are many species under the genus. Some of the species are mentioned below. They are: *Rana temporaria* (common European grass-frog), *R. esculenta* (common water-frog of Europe, Asia and Africa), *R. sylvatica* (North America), *R. catesbeiana* (bull-frog of North America), *R. tigerina* (bull-frog of India), *R. hexadactyla* (common Indian grass-frog), *R. limnocharis* (rice-field frog of India) and *R. cyanophlyctis* (common water-frog of India).

RHACOPHORUS. *Rhacophorus* is a common tree-frog. The webbed hands and feet are greatly enlarged so as to act as parachutes. *Rh. malabaricus* can glide from the branches of tree to the ground and covers a horizontal distance of about 9 m. *Rh. maculatus* is the common Indian tree-frog. In this animal, the tip of all the digits becomes enlarged to form adhesive discs. These discs produce a sticky secretion by the help of which, this animal can adhere to any object. The eggs are laid in water in all the species, but in *Rh. reticulatus* of Ceylon, the eggs are attached to the ventral surface of the belly.

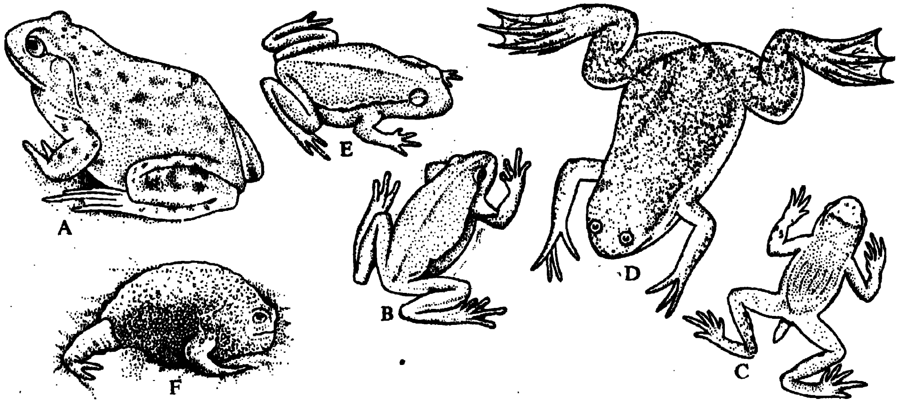


Fig. 6.27. Some anurans. A. *Rana*. B. *Hyla*. C. *Ascaphus*. D. *Xenopus*. E. *Liopelma*. F. *Breviceps*.

HYLA. *Hyla* is a tree-frog (Fig. 6.27B). The terminal phalanges are claw-like and swollen at the base to form adhesive pads by which it can climb the trees or vertical walls of the buildings or rocks. The upper jaw is toothed. All the tree-frogs, excepting *Hyla arborea* of India and Southern China, are exclusively restricted to America or Australia. *Hyla venulosa* of the lower Amazon can glide from a considerable height. Parental care is well-developed. *H. faber* makes mud-nests for laying the eggs and *H. goeldii* carries the eggs on the back of the female.

PIPA. *Pipa* is a specialised aquatic toad of South America. The tongue and teeth are absent. Pipa shows an advanced condition for the care of the youngs. There is an elaborate arrangement for the development of the youngs within pits on the back of the females.

XENOPUS. *Xenopus* (Fig. 6.27D) is an African toad and closely related to Pipa. There is no tongue. The tympanum is indistinct. The vertebrae are opisthocoelous. The upper jaw is toothed. The pupil is round. The phalanges are pointed. The digits of the forelimbs are free, while that of the hindlimbs are webbed and the first three bear horny claws. Parental care is absent. The tadpole has a pair of branchial openings.

LIOPELMA. *Liopelma* (Fig. 6.27E) is found in New Zealand. It has many primitive features. The tail muscles are present which are absent in other anurans. The vertebrae are amphicoelous. The ribs are free and the abdominal ribs are present. The posterior cardinal veins are present.

ASCAPHUS. *Ascaphus* (Fig. 6.27C) is a primitive frog inhabiting the mountain streams of Northern America. The lungs are reduced. The fertilization is internal and is assured by a penis-like extension from the cloacal chamber.

BREVICEPS. *Breviceps* (Fig. 6.27F) is a specialised anuran which is adapted to burrowing. It digs the soil for ants as food. The snout is greatly enlarged and the limbs are modified. The Indian burrowing forms are *Uperodon globulosum* which leads a subterranean life.

CLASSIFICATION

The scheme of classification of the class Amphibia presented in this text is based on the principles adopted by Noble (1954).

CLASSIFICATION IN OUTLINE

Class Amphibia

Extinct orders

Order *Labyrithodontia*
 Suborder Embolomeri, e.g., *Palaegyrius*.
 Suborder Rachitomi, e.g., *Eryops*.
 Suborder Stereospondyli, e.g., *Capitosaurus*, *Cyclotosaurus*.
Order *Phyllospondyli*, e.g., Branchiosaurs and allies.
Order *Lepospondyli*
 Suborder Nectridia, e.g., *Diplocaulus*.
 Suborder Aistopoda, e.g., Carboniferous Sirens and Amphiumas.
 Suborder Gastrocentrophori, e.g., Salamander-like Lepospondyls.
 Suborder Adelospondyli, e.g., *Lysorophus*.

Living orders

Order *Gymnophiona* (or *Apoda*), e.g., *Ichthyophis*.
Order *Urodela* (or *Caudata*)
 Suborder Cryptobranchoidea, e.g., *Cryptobranchus*.
 Suborder Ambystomoidea, e.g., *Ambystoma*.

Suborder Salamandroidea, e.g., *Triton*, *Desmognathus*.
Suborder Proteida, e.g., *Proteus*.
Suborder Meantes, e.g., *Siren*.
Order *Salientia* (or *Anura*)
Suborder Amphicoela, e.g., *Ascaphus*.
Suborder Opisthocoela, e.g., *Alytes*, *Pipa*.
Suborder Anomocoela, e.g., *Pelobates*.
Suborder Procoela, e.g., *Bufo*, *Hyla*.
Suborder Diplasiocoela, e.g., *Rana*.

CLASSIFICATION WITH CHARACTERS

The amphibians are classified into three extinct and three living orders. The classification of the extinct amphibians is incomplete and is based largely on the fragmentary fossil evidences.

Extinct orders

The fossil amphibians are included under three orders. The orders are: *Labyrinthodontia*, *Phyllospondyli* and *Lepospondyli*.

Order *Labyrinthodontia*. The members of this order were Salamander-like amphibians of the lower Carboniferous to Triassic periods. They are usually called the Stegocephalians or Labyrinthodonts. Stegocephalians constituted a very important group because they gave origin to the first reptilian form. They were fully aquatic as evident by the presence of well-developed lateral line canals in the skull. The skull was provided with heavily armoured bony plates. The teeth were large and were provided with greatly folded dentine. The skull was completely roofed by bones. This order includes three Suborders: *Suborder* (1) Embolomeri with double centra in the vertebrae. Example: *Palaegyrius*. *Suborder* (2) Rachitomi was characterised by having half-mooned intercentra. Example: *Eryops*. *Suborder* (3) Stereospondyli included the family Capitosauridae. The pleurocentrum was rudimentary or absent. Example: *Capitosaurus*.

Order *Phyllospondyli*. This order comprised of small urodela-like creatures. This group holds the ancestry of the modern amphibians excepting the caecilians. The notochord and the nerve cord remained in the same cavity. Two occipital condyles were present in the skull. The Branchiosaurs and their allies are included in this order.

Order *Lepospondyli*. The members of this order are regarded to be the progenitors of the caecilians. The vertebrae were cylindrical and each vertebra was composed of single piece of bone. The neural arch was fused with the centrum. This order includes four suborders: *Suborder* (1) Nectridia. Besides the zygapophyses, extra attaching processes, zygantra and zygosphenes were present in the vertebrae. Example: *Diplocaulus*. *Suborder* (2) Aistopoda. They were all limbless forms. The vertebrae possess distinct transverse processes. Examples: Sirens and Amphiumas of Carboniferous. *Suborder* (3) Gastrocentrophori. This suborder is incompletely studied and its relationship with the other suborders is not well defined. Examples: Amphiuma-like lepospondyls. *Suborder* (4) Adelospondyli. The neural arch was joined with the centrum by suture. Example: *Lysorophus*.

Living orders

The caecilians, urodeles and anurans constitute the members of the three living orders of the class Amphibia.

Order *Gymnophiona* (or *Apoda*)

This order includes the elongated, snake-like and limbless creatures usually called the caecilians. The caecilians are all living and have no fossil representative. They live in burrows and exhibit the basic features of fossorial adaptation. The anus is located terminally and the post anal tail is absent or extremely short. The surface of the skin is transversely grooved. Beneath the grooves of the skin, groups of minute scales are present. The scales are absent in *Typhlonectes*, *Siphonops*, *Bdellophis* and *Gegenophis*. The lidless eyes are rudimentary and remain usually hidden under the skin. Presence of a protrusible sensory tentacle in between the nostril and the eye is a peculiar occurrence. The male is provided with a large protrusible copulatory organ. The vertebrae are amphicoelous. The frontal and the parietal bones of the skull are separate. The eggs are large and yolky. The cleavage is meroblastic. As the eggs are laid on land, the embryos grow utilising the yolk. The youngs possess plumed external gills. The aquatic genus, Typhlonectes has a flattened tail and the development is internal.

Order *Urodela* (or *Caudata*)

The order Urodela includes the tailed amphibians and represents a very important group, because they form the hypothetical stage between the fishes and amphibians.

The urodeles have lizard-like elongated body with two pairs of subequal limbs. The limbs are usually weakly developed. The post anal tail is well-developed. The mouth is terminal in position and is bounded by a pair of jaws. The teeth may or may not be present. The eyes are small and have no eyelid. There is no tympanum. There is no exoskeleton and the chromatophores are embedded in the deeper layer of the skin. In Asiatic urodele, *Onychodactylus*, small horny claws are present.

The skull differs from that of toad by many important points. The cartilage in the cranium is very much restricted. The trabeculae do not fuse and the cranium is complete above and below in the parachordal or occipital region. The roof and floor of the skull are provided with a large supracranial and a basicranial frontanelle. The former frontanelle is covered by the parietals and frontals and the latter by the parasphenoid. The parietals and frontals are separate. The parasphenoid is not sabre-shaped. The vomer and palatine are fused to form vomeropalatine which bears teeth. The quadrate is directed forward and may be situated at right angle to the axis of the skull. The vertebral column consists of a large number of vertebrae. The total number of vertebrae may reach 250. The vertebrae may be amphicoelous (the centra are concave) or opisthocoelous (convexity on the anterior and concavity on the posterior face of each centrum). The first vertebra has an odontoid process. The first vertebra in adult is actually the second vertebra, because the original first one is absorbed in the skull. The transverse processes are bifurcated and the double-headed ribs are attached to the transverse processes. The caudal vertebrae are provided with haemal arch through which the blood vessels pass.

The pectoral girdle is simple and composed mainly of cartilage (Fig. 6.28). Two coracoids overlap one another. The scapulae are ossified. The clavicles are absent. The sternum is peculiar and appears to be associated secondarily with the pectoral girdle. The pelvic girdle consists of a large cartilaginous plate-like pubis. The ilium and ischium undergo ossification. The ilia articulates with the first sacral vertebra. There is an 'Y'-shaped *Ypsiloid bone* or *epipubis* attached to the pubis. A rod-like nodule may develop as the prepubic cartilage. The limbs are peculiar. The radius and ulna are completely separate. The tibia and fibula also exist as separate bones. The tarsal bones are usually distinct and retain the primitive arrangement. The forelimbs have four digits.

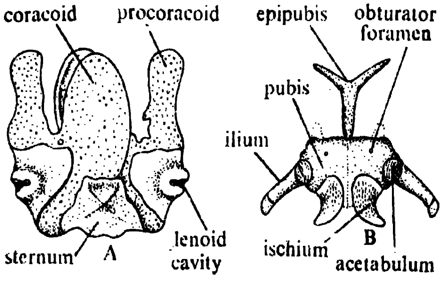


Fig. 6.28. Girdles of Urodeles. A. Pectoral girdle of *Ambystoma*. B. Pelvic girdle of *Salamandra*.

The tongue is fixed and immovable. The intestine becomes elongated and forms several loops. Respiration usually occurs by the gills in the larval stages, but the adults respire mostly by the lungs and skin. The lungs are absent in Desmognathus where respiration is exclusively cutaneous and pharyngeal. Each lung is a simple sac-like structure (Fig. 6.29). A long trachea may be present. Cutaneous gills remain covered by the ectodermal cells. In salamanders, the lungs also act as the hydrostatic organ. The heart consists of two auricles and one ventricle. The inter-auricular septum is fenestrated. In cases where lungs are absent, a large foramen ovale is present. The conus arteriosus has valves. The typical spiral valve may be absent. Usually four pairs of aortic arches are present. In cases, where the gills persist in adult, accessory loops are present in the third, fourth and fifth arterial arches.

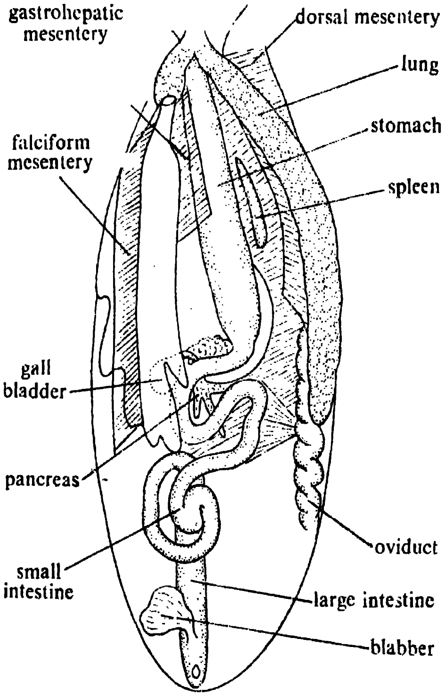


Fig. 6.29. Showing the disposition of the major visceral organs in an urodele, *Necturus*.

Fig. 6.30 shows the arrangement of the arterial arches in a larval and adult urodele. The venous system is a transitional type between that of fishes and anurans. The erythrocytes are oval, nucleated and are remarkable for their unusual size. In *Amphiuma*, the size of erythrocyte measures about 80 micra and that of *Proteus* measuring about 58 micra.

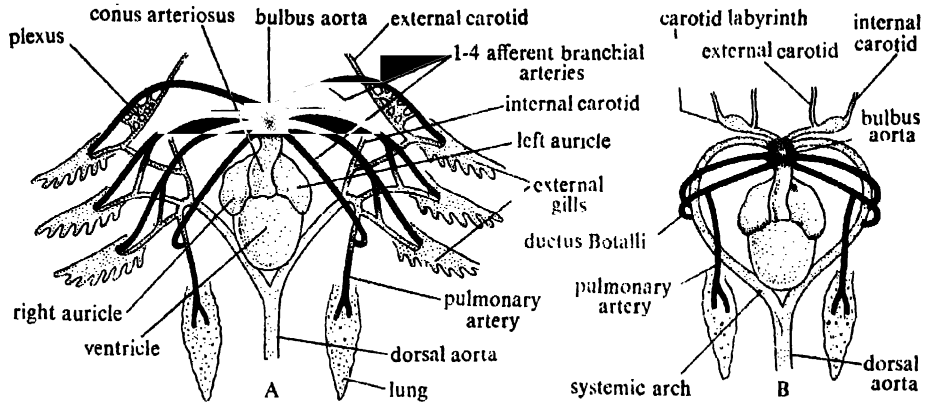


Fig. 6.30. Anterior arterial arches of *Salamandra*. A. Larval condition. B. Adult.

The brain is relatively simple (Fig. 6.31). The cerebral hemispheres are extremely elongated. The optic lobes are comparatively small in size. The olfactory bulbs are not united. The eyes are small and functionless, especially in cave-dwelling forms. The eyelids may be absent as in the family Salamandridae. The columella in the middle ear is absent. The lateral line sense organ is present in the larvae. The kidney is opisthonephros type. The anterior portion of the kidney is nonrenal while the posterior part is functional. The urinary bladder is not bilobed. The segmental nature of the nephric ducts is retained in the adult stage. The elongated testis often shows segmental nature. From the testis, several vasa efferentia run out and enter into the nonrenal part of the kidney. The nonrenal part of the kidney shows the hint of formation of epididymis. In male, a narrow cord-like structure is present by the side of the urinogenital duct. This cord represents the Mullerian duct. The ovary is an elongated sac-like structure. The oviduct is tubular. The terminal part is not dilated to form uterine chamber. Fertilization is generally internal. A very interesting case of paedomorphosis is furnished by the Axolotl larva of Ambystoma.

The order Urodela includes five suborders. The suborders are:

Suborder Cryptobranchoidea

This suborder includes the most primitive urodeles. They are characterised by having the following features: (1) The angular of the lower jaw remains free and is not fused with the prearticular. (2) The premaxillary spine is short. (3) Fertilization is external. (4) The cloacal gland is complex in nature. This suborder includes two families: Hynobiidae and Cryptobranchidae. The family Hynobiidae is represented by five genera, of which *Hynobius* is the most common one. The family Cryptobranchidae has two genera, *Cryptobranchus* and *Megalobatrachus*. The most important example of Cryptobranchidae is *Cryptobranchus elleganiensis* of the United States of America. They are giant urodeles and semilarval in adult. The eyes are small and lidless. The lateral line sense organs are present. The gills are absent in adult, but the spiracle remains opened. Megalobatrachus is found in China and Japan. It is less larval in nature than Cryptobranchus.

Suborder Ambystomoidea

The members of this suborder possess many advanced characteristics over the Cryptobranchoidea. The angular is fused with the prearticular. The premaxillary spine is enlarged. The vertebrae are amphicoelous in nature. The hyoid apparatus is peculiar by having a cartilaginous cross bar between the posterior cornua. Fertilization is internal. The adults of most species lack larval characters. But one species, *Ambystoma tigrinum* presents a neotenic form—the *Axolotl* of the mountain regions in Mexico. Lack of iodine and extreme cold water prevent the Axolotls to metamorphose into the adults. But administration of thyroxine (hormone secreted by the thyroid glands) causes the Axolotls to switch over into their adulthood.

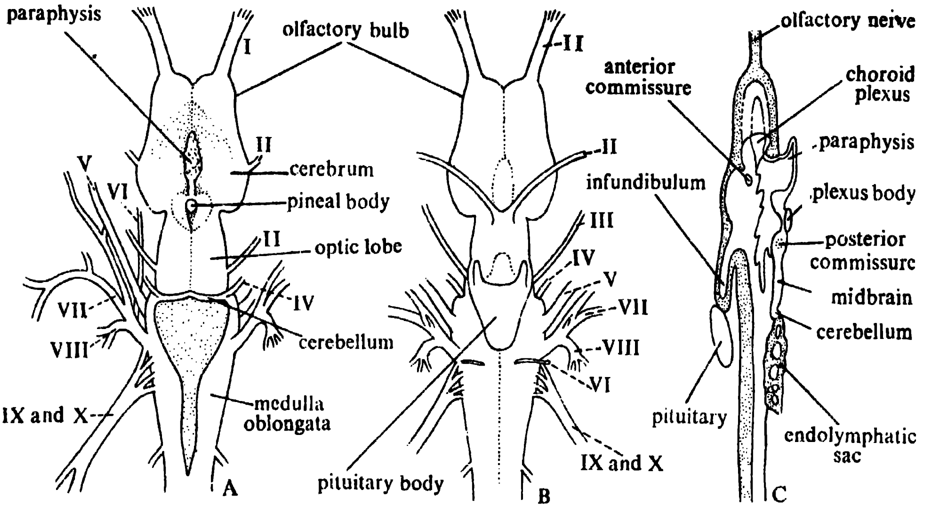

paraphysis
I
olfactory bulb
II
V
VI
cerebrum
pineal body
II
optic lobe
IV
VII
VIII
cerebellum
IX and X
medulla
oblongata
A
II
anterior
commissure
II
infundibulum
III
IV
V
VII
VIII
VI
pituitary body
IX and X
B
olfactory neive
choroid
plexus
paraphysis
plexus body
posterior
commissure
midbrain
cerebellum
pituitary
endolymphatic
sac
C

Fig. 6.31. Brain and cranial nerves in an urodele, *Necturus*. A. Dorsal view. B. Ventral view. C. Diagrammatic longitudinal sectional view. I-X represent the corresponding cranial nerves.

Suborder Salamandroidea

This suborder includes three families: Salamandridae, Plethodontidae and Amphiumidae. The Salamandroidea is characterised by the possession of the following features: (1) The vertebrae are usually opisthocoelous. (2) Teeth are present on the roof of the palate. (3) The prevomers are either extended backward as two dentigenous processes on either side of the parasphenoid or break up into one or two sets of tooth patches lying on the parasphenoids. (4) Three sets of cloacal glands are present. (5) Fertilization is internal.

The family Salamandridae is represented by the typical newts. *Triturus* (the American genus) and *Triton* (the European genus) are the typical examples of the family. *Tylototriton* is the most primitive salamandrid and is reprsented by two species *T. verracosus* (found in eastern Himalayas) and *T. andersoni* (in Okinawa island in the Loochoo Archipelago). The family Salamandridae is characterised by having prevomerine teeth arranged in 'S-shaped' row on each side of the parasphenoid. The family Plethodontidae represents majority of the American urodeles. They are all terrestrial forms. The lungs are absent and the animals respire by the skin. A nasolabial groove is present which assists in freeing the nostrils from water. The Ypsiloid apparatus is reduced or absent. *Desmognathus* and *Spelerpes* are the well known genera. *Typhlomolge* is the only neotenic form under the family. It has external gills and it is fully blind. The family Amphiumidae includes the 'Congo eels' which is represented by the genus, *Amphiuma*. Amphiuma is a semilarval form and has a very long cylindrical body. The limbs are vestigial. The eyes are lidless. One small pair of gill-slits is present.

Suborder Proteida

This group comprises of the Mud puppy, *Necturus* and the blind cave dweller, *Proteus*. They are permanent larval forms. They possess the following characteristics. (1) The lungs are absent. (2) The eyelids are absent. (3) Long external gills are retained. (4) The fourth branchial arch is lost in adult. (5) The Ypsiloid apparatus is absent. (6) The skull is largely cartilaginous. (7) The maxillae are absent.

Suborder Meantes

This group contains the 'Sirens'. They are permanent larval forms, which do not attain adult characters. Only the anterior appendages are present. There are three pairs of external gills. The eyes are lidless. The premaxillary spine is small. The maxillaries are absent. This suborder includes one family—Sirenidae with two genera, *Pseudobranchus* and *Siren*.

Systematic status of Urodela

The systematic status of the urodela is controversial due to its peculiar anatomical organisation. Anatomically, urodeles form a transitional group between the fishes and amphibians. They show structural similarities with the fishes in one hand and with the amphibians on the other.

Relationship with the fishes.

Urodeles exhibit the following piscine features. These are: (1) Presence of immovably fixed tongue. (2) The lateral line sense organ is present. (3) The gills are present. (4) The circulatory and excretory systems show many similarities. (5) The tympanum is absent. Besides these typical piscine features, the urodeles show some similarities with crossopterygians. The resemblances are: (1) the presence of cutaneous gills, (2) similar girdles, (3) similarly disposed visceral arches, (4) similar heart and arterial arches, (5) similar venous system, (6) first spinal nerve is without dorsal root and (7) the ypsiloid bone of urodele is comparable to the epipubic bone of the dipnoans. The similarities with the fishes in general and with the crossopterygians in particular speak of their phylogenetic relationship.

Relationship with the amphibians.

The urodeles are included in the order Urodela under the class Amphibia. This fact needs no consideration, because the organisation of the brain, circulatory system, skull and visceral arches are typically amphibian in nature. Amongst the amphibians, the urodeles are to be regarded as a very primitive group than anurans because the position of the quadrate justifies the truth. The primitive characters of the urodeles are due to their retention of the larval features. Within the order Urodela a gradation of organisation is observed:

Grade I. Urodeles with persistent gills (*Perennibranchiate condition*) e.g., *Necturus*, *Proteus* and *Siren*.

Grade II. Absence of gills and presence of only gill-slits in adult (*Derotrematous condition*) represents the transitional stage, e.g., *Amphiuma*.

Grade III. Absence of gills and gill-slits in adult (*Caducibranchiate condition*) is the most advanced forms, e.g., *Megalobatrachus*, *Salamandra*, *Triturus*.

Order *Salientia*

The order Salientia includes the toads and frogs. This order is also named as Anura or Batrachia Ecaudata or Batrachia. The members of this order are regarded to be the highly developed forms amongst the amphibians. They are characterised by having many specialised characteristics. These are: (1) The body is short and broad. (2) The post anal tail is absent. (3) The limbs are well-developed. The hindlimbs are longer than the forelimbs and are four jointed. (4) The eyelids are well-formed. (5) The tympanum is distinct. (6) The frontal and parietal bones of the skull are mostly fused to form frontoparietals. (7) The mandible is devoid of teeth. (8) Neoteny is not observed in the larval forms. (9) There is no trace of external gills and gill-slits in adult.

The order Salientia includes five suborders depending on the nature of the centra. The suborders are:

Suborder Amphicoela

The members of this suborder are regarded to be the most primitive anurans and are characterised by having amphicoelous vertebrae. This suborder includes only one family, Liopelmidae. Examples: *Ascaphus*, *Liopelma*.

Suborder Opisthocoela

This suborder is represented by two families, Discoglossidae and Pipidae. They have opisthocoelous centra and short scapulae. The ribs are free. The members of the family Pipidae are tongueless. Examples: *Alytes*, *Pipa*, *Xenopus*.

Suborder Anomocoela

The vertebrae of the forms included under the suborder are procoelous in nature. Free ossified ribs are absent. The ninth vertebra is usually fused, if free, only one articular condyle is present. Family Pelobatidae is included under this suborder. Examples: *Pelobates*, *Sooglossus*, *Megophrys*, *Nesomantis*.

Suborder Procoela

This suborder embraces three living families, Bufonidae, Brachycephalidae and Hylidae and one extinct family, Palaeobatrachidae. The vertebrae are procoelous. The urostyle articulates with the posterior end of the ninth vertebra by two condyles. Examples: *Bufo*, *Dendrobates*, *Hyla*, *Hylorina*, *Nectophrynoides*, *Pseudobufo*, *Brachycephalus*.

Suborder Diplasiocoela

This suborder is examplified by the true frogs. The vertebrae are procoelous except the eighth one which has amphicoelous centra. The centrum of the ninth vertebra shows convexity anteriorly and it bears double condyles posteriorly. This suborder includes three families: Ranidae, Polypedotidae and Brevicipitidae. Examples: *Rana*, *Polypedates*, *Breviceps*.

GENERAL NOTES ON AMPHIBIA

The living amphibians exhibit diverse structural adaptation. The caecilians have a degenerated structural organisation and they furnish all the basic modifications for fossorial life. They are the most primitive forms amongst the living amphibians. The modern urodeles have a large number of families and genera. Although built on a common fundamental plan, each family is characterised by having peculiar anatomical structures. The urodeles include many giant forms. The largest amphibia is the *Megalobatrachus* which may even reach a length of about 1.60 m. Most of the urodeles are aquatic. The terrestrial forms have limbs and are plantigrade. Anatomically, the urodeles occupy an intermediate position between the caecilians and the anurans. The anurans constitute the highly specialised forms and show wide range of adaptive radiation. *Hyla* shows an adaptation for arboreal life and possesses adhesive discs at the tip of the digits. The plate-like adhesive discs are not suctorial in action, but have a moist, corrugated antiskid surface which helps in adhesion to the tree. During climbing, a sticky secretion is expelled from the adhesive discs by the action of collagenous fibres which operate the glands. The adjustment of the adhesive discs is facilitated by the development of *intercalary cartilage* between the terminal and penultimate joints. Another tree-frog, *Chiromantis*, has opposable digits. In most of the tree-frogs, the webs between the toes are absent or reduced, excepting in *Rhacophorus* of East Africa where the elongated digits are webbed. It has been recorded that *Rhacophorus malabaricus* can glide from a height of more than 9 m and *Hyla venulosa* can glide from a height of 42 m quite effectively. In *Hyla venulosa* the digits are not webbed.

SKIN

The skin of amphibians consists of epidermis and dermis. The epidermis consists of several layers and is renewed by ecdysis. This process of renewal is controlled by the pituitary and thyroid glands. Localised thickening in epidermis is observed in the larvae, specially in the formation of the horny larval jaws and teeth. The warts of toad are also the instances of such thickenings. The skin of modern amphibians is naked and remains moist due to the secretion of integumentary glands. The moist skin is necessary for respiration and also possibly for temperature regulation. There are two types of skin glands in amphibians. These are: *mucous glands* and *poison glands*. The mucus secreted by the mucous glands keeps the skin moist. The poison glands are well-developed in toad and salamanders. The parotid glands of toad are the best examples of the poison glands. Most of the warts on the dorsal surface of the toad open to the exterior by a minute opening which leads into poison gland. The gland produces active toxins. The secretion is venomous and causes nausea, respiratory and cardiac disfunctions. The toxins are isolated as the *bufogin* and *bufotalin*. The poison of *Dendrobates* acts on the nervous system. The secretion of the dorsal glands of a warty Newt (*Triturus cristatus*) is venomous. The poison glands are defensive organs. The skin of the larval amphibians is ciliated. The colour of the skin of amphibia may vary from dull to brilliant. The urodela usually shows brilliant colouration which has a protective value. The green colouration of tree-frogs is a protective device, because it harmonises with the surrounding green foliage. The spotted salamander and some frogs exhibit warning colouration. In some tree-frogs, the brightness of the body colouration may vary with the change of intensity of light. The colour change is caused by the physiological adjustment of the deeply seated melanophores, guanophores and overlying lipophores.

SKELETAL STRUCTURES

Exoskeleton. The exoskeleton was present in fossil amphibians. But in modern forms it is restricted to majority of the caecilians and some anurans. In caelicians, clusters of small dermal scales lie in the skin in most of the cases. In a few toads, bony plates remain embedded in the skin of the back and these are dermal in origin. In *Brachycephalus* of Brazil, the dermal plates on the back become fused with the neural spines. Small and horny claws are present in an Asiatic urodele, *Onychodactylus* and in an African toad, *Xenopus*. In *Pelobates*, the highly cornified areas on the feet can be compared with the epidermal scales.

Endoskeleton. The *skull* in the living amphibians varies greatly. There is a general tendency towards reduction in the thickness and number of dermal elements. The interpterygoid vacuities and the orbits are greatly enlarged. The rami of the lower jaw are short and the skull becomes much flattened. The skull of the anurans is highly specialised amongst the amphibians. The interparietal foramen (present in fossil amphibians) is totally absent in modern amphibians. The skull of toads is devoid of teeth, but in *Amphignathodon* true teeth are present on the lower jaw. In frogs, teeth are present on the upper jaw. The skull of urodeles has certain peculiar features of its own. It is less specialised than that of anurans and differs in many important respects. The chondrocranium is of lower organisation with many degenerative or paedomorphic features. The parietals and frontals are separate and in some forms both lacrimals and prefrontals are persistent. The skull of urodeles differs from that of anurans by having a large prevomer. In caecilians, the skull is peculiar. It has large investing bones and a small but complete orbit is present there. The skull is a rigid structure. The compactness is correlated with the burrowing habit. The lower as well as the upper jaws bear teeth. Like that of urodeles, a tooth-bearing coronoid is present in the mandible.

The vertebral column in amphibia is largely bony and the vertebrae are articulated together. The flexibility of the vertebral column is lost to give more strength. This modification is due to the lifting of the body on the limbs. In urodeles which spend much of the time in water, the vertebrae lack ossification and notochord persists to help in swimming. The transition from aquatic to terrestrial life causes the shortening of the vertebral column. In anurans, the vertebral column is composed of nine vertebrae and an unsegmented *urostyle* behind. The vertebral column is differentiated into: (1) the cervical region represented by the *atlas*, (2) the thoracolumber region with variable number of vertebrae, (3) a sacral region containing a large vertebra and (4) a caudal region comprised of the tail vertebrae. The urostyle represents the caudal region in anurans. The transverse processes and zygapophyses are well-developed for the attachment of muscles. The number of vertebrae is variable. It may extend upto 250 in urodeles and caecilians. In anurans, the vertebrae are *procoelous* except the ninth vertebra of *Rana* which is *opisthocoelous*, i.e., the anterior surface of centrum is convex while the posterior surface is concave. But in urodeles, two types of vertebrae are encountered. The primitive urodele as examplified by *Ambystoma* has *amphicoelous* vertebrae and the higher urodeles possess opisthocoelous vertebrae. Some primitive frogs examplified by *Ascaphus* and *Liopelma* have free ribs. The skeletal features of the girdles and limbs have changed considerably in amphibians. The basic plan of the limbs and girdles remain same throughout the group. In caecilians these are secondarily lost due to fossorial adaptation. The peculiarities of the appendicular skeleton in urodeles and anurans have already been discussed. In the fishes, the girdles and paired fins are small and are largely cartilaginous, but in amphibians the girdles have become greatly enlarged and modified due to their weight-bearing function. The appendicular skeleton in urodeles is greatly simplified, but in anurans these are highly developed and are quite suitable for terrestrial mode of life.

DIGESTIVE SYSTEM

The adult amphibians feed mostly on the arthropods, but the larval forms are usually omnivorous. They may be cannibals. As a result of similar food habits, the digestive system shows little variation. In most amphibia excepting the toads, the teeth are present. The teeth are borne on the premaxillae, maxillae and vomer. The teeth are very small and pointed and are used only to catch the prey. Biting teeth are present in adult *Ceratophrys ornata*. *Amphignathodon*, a South American tree-frog, possesses teeth on the lower as well as on the upper jaws. The salivary glands are absent but some oral glands are present which produce mucus. In terrestrial amphibians, cilia are present in the oral cavity which keep the oral fluid in movement. In case of many urodeles tongue is immovably fixed. It may be movable as in most anurans but it is free behind and fixed anteriorly. The tongue is used to capture the prey. The adhesive powei of the tongue is enhanced, particularly in the frogs, by the secretion from the *lingual* and *internasal glands*. The tongue is altogether absent in Xenopus and Pipa.

The oesophagus is a simple tube and is not sharply distinguishable from the stomach. The stomach is simple with folded mucous layer. Simple tubular gastric glands open in the folds. These glands are composed only of one type of cells. The glands produce pepsin and hydrochloric acid. The intestine is short in adult amphibians and is marked off from the stomach by having a well-developed pyloric sphincter. But the intestine in omnivorous larval forms is much coiled like the spring of a clock.

The liver and the pancreas have typical histological picture and produce bile and pancreatic juices. The amphibian can live for a considerable period of time without taking any food. The cave-dwelling urodeles are the typical examples. Axolotl larva may remain alive for about 650 days in starvation.

RESPIRATORY SYSTEM AND SOUND PRODUCTION

The adult amphibians are lung-breathers. The skin acts as an accessory respiratory organ both in water and on land. The skin is highly vascular and specially so in the buccopharyngeal cavity. The larval amphibians respire in water by the gills. Such gills are retained in many adult urodeles. Few urodeles retain *external gills* as the respiratory organs in adult. Both external and internal gills are present in anuran larvae. Ascaphus, living in the mountain stream of U.S.A., has reduced lungs. It helps the animal to live in water. In perennibranchiate urodeles the lungs are simple saccular organs and the hydrostatic function is predominant. In *Salamandra atre* and *Desmognathus*, the lungs are absent. In *Astylosternus*, an African frog, the lungs are vestigial. In caecilians the tracheal lung may be present but the left one is always rudimentary. In aquatic urodeles, the lungs act secondarily as hydrostatic organ. In all these above cases, respiration is exclusively pharyngeal and/or cutaneous. In almost all amphibians cutaneous respiration is a remarkable supplementary respiratory adaptation. In *Cryptobranchus*, there are vascular folds in the epidermis into which blood capillaries penetrate.

The amphibians are virtually the pioneers where true voice is produced by the vocal organ. The production of sound is a protective response for fear and the males call the females during breeding season. The noise is produced by the vibration of the vocal cords in the laryngotracheal chamber. The vocal sacs in the males of some anurans, developed as the buccal outgrowths, subserve as resonator.

CIRCULATORY SYSTEM

The heart of amphibia consists of a sinus venosus, two auricles, an undivided ventricle and a conus arteriosus. The left auricle is absent in the plethodontid urodeles where the lungs and the pulmonary veins are missing. The auricles are completely separated by a complete interauricular septum. It is perforated in *Salamandra* or may be fenestrated with intervening spaces in lungless urodeles. The venus blood returns to the right auricle while the left auricle receives oxygenated blood. The spiral valve is present in anuran heart but it may be reduced in urodeles or absent as in *Necturus*, *Cryptobranchus* and the caecilians. In all the amphibians where the conus arteriosus is present there are two sets of valves which prevent the back flow of blood. In the urodeles where gills are retained in adults, the pattern of circulatory system is essentially fish-like. The venous system of the urodeles represents a transitional stage between the fish and the anurans. The R.B.C. in amphibia is nucleated and oval. One of the notable features to record is the presence of largest R.B.C. amongst the vertebrates. There are three types of leucocytes in amphibians. These are lymphocytes, monocytes and polymorphs.

NERVOUS SYSTEM

The brain of amphibia is basically built on the same fundamental plan in all forms. The prosencephalon is represented by two large evaginated cerebral hemispheres. The pineal organ is a simple sac in most cases, but in a few amphibians this forms a retina-like structure. The optic lobes are well-developed. As the amphibians are sluggish animals, the cerebellum is simple.

Sense organs

The sense organs are well-developed. Many aquatic adult amphibians and the larvae possess simple lateral line organs in the form of clusters of cells in an open pit. The skin contains tactile sense organs and chemoreceptors. The olfactory organ works both in water and on land. *Organ of Jacobson* is present in most amphibians. It is a special sensory sac developed as a diverticulum from the olfactory chamber. It serves to test the scent of the food taken inside the mouth. It is absent in Proteus and Necturus.

Eyes. The eyes of amphibia exhibit certain modifications due to transition from water to land. In water the eyes were adapted for short-sighted vision but on land long-sighted vision becomes necessary. The eyes are extremely degenerated in caecilians and also in cave-dwelling urodeles. The eye-ball is more or less spherical with a rounded cornea. The lens is flattened in terrestrial amphibians, but in aquatic forms it is rounded. The eyelids are usually present in terrestrial forms excepting some primitive members. In tree-frogs, the eyelids may be transparent. The lacrymal glands are present in all the terrestrial amphibians. In aquatic amphibians the lacrymal glands are absent but the lacrymal ducts are still retained in many cases. In some caecilians, a single lacrymal gland occupies a position in the sightless eye-socket to lubricate the sensory tentacle. In all amphibians the skin is also sensitive to light. This is highly developed in cave-dwelling urodeles.

Ear. The membranous labyrinth is composed of an utriculus with three semicircular canals, a sacculus with an outgrowth called the lagena. The middle ear consists of a funnel-like cavity which communicates with the pharyngeal cavity by eustachian tube. In this cavity, a rod (columella) is present which transmits the sound waves to the internal ear. The columella fits into the fenestra ovalis by a broad foot (*otostapes*). The fenestra ovalis is partly occupied by a plate (*operculum*). So the transmiting rod is divided into an inner part (otostapes and operculum), a medium part called the *mediostapes* and an outer part designated as the *extracolumella*. In urodeles, caecilians and some anurans, the trympanic cavity and extracolumella may be absent. Cryptobranchus lacks the operculum. This is also absent in Xenopus and Pipa. In a terrestrial anuran, *Bombinator*, the tympanum and columella are greatly reduced.

URINOGENITAL SYSTEM

The kidneys in amphibia are of opisthonephric type and retain the characteristics of fishes. The shape of the kidneys corresponds to the shape of the body. In urodeles and in a primitive frog, Ascaphus the kidneys are elongated. Each kidney is divided into an anterior narrow nonrenal part and a broad posterior renal part. In caecilians the kidneys are also extremely elongated and occupy the whole length of the body cavity. In case of anurans the kidneys become condensed and divided into lobes.

In amphibians, the genital organs develop from the genital ridges. Each such ridge is situated on the ventromedian aspect of the developing mesonephros. The genital ridge is divided into three sectors: (1) anterior part (*progonalis*), (2) middle part (*gonalis*) and (3) posterior (*epigonalis*). The gonads proper develop from the gonalis. In anurans, the fat bodies develop from the progonalis while in the urodeles and caecilians, the fat bodies develop from the entire genital ridge. The testes in different amphibia assume various shapes. In caecilians, each testis is an elongated body and looks like a string of beads. The testes discharge through the kidneys by the vasa efferentia. So the Wolffian or mesonephric duct serves as an urinogenital duct in male and as an ureter in female. In toads, a special Bidder's organ is present. This organ is better developed in males. The function of this organ is not known. It is assumed to be an endocrine organ, because it undergoes a cycle of size change. This organ is capable of developing into an ovary after castration in either sex. The Bidder's organs develop from the gonalis sector just anterior to the gonad proper. The Mullerian duct is transformed into the oviduct in female. The female gonoduct becomes modified in accordance with the modes of reproduction. In anurans the uteri exhibit great modification. Bhaduri has classified the uterus of anurans into three broad categories (Fig. 6.32): (1) *Uterus separatus*, (2) *uterus septatus* and (3) *uterus communis*. In *Rana* and *Xenopus* two uteri remain separate along their course and open into the cloaca by independent opening. This condition is called the *uterus separatus*. In *Bufo* and *Rhinoderma* a septum runs anteroposteriorly between two uteri, but posteriorly form a common uterus by fusion at the the terminal ends. This condition is called *uterus septatus*. The two uteri have a common opening into the cloaca. The degree of fusion varies greatly and finally in *Dendrobates* two uteri become confluent into an unpaired common uterus. The median partition wall between the uteri is absent. This type of uterine condition is called the *uterus communis*. The uterus separatus is comparable with the duplex type, the uterus septatus with the uterus bipartite and uterus bicornis types and the uterus communis with the uterus simplex of the mammals.

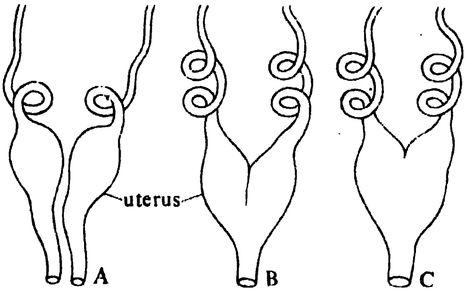


Fig. 6.32. Uterus in anurans. A. Uterus separatus in *Rana*. B. Uterus septatus in *Rhinoderma*. C. Uterus communis in *Dendrobates*.

REPRODUCTION AND DEVELOPMENT

In majority of the amphibians, external fertilization is the rule. They are oviparous. But several instances of ovoviviparous condition are encountered. In case of *Salamandra atra* the eggs are retained inside the oviduct where intrauterine development occurs. In most urodeles, the spermatozoa are transferred to the body of the female in the form of *spermatophores*. In almost all amphibians the ontogenic development is indirect, i.e., accompanied by well-marked metamorphosis. Most of amphibians undergo complete metamorphosis but some urodeles retain the larval features and become neotenic. The most remarkable instance of neotenous form is the *Axolotl* which breeds in larval state.

PARENTAL CARE

The amphibians were the pioneers amongst the vertebrates to invade the land. On coming to this new environment they had to face many hostile forces and they had to develop various ways and means to overcome the obstacles. Naturally the greatest importance was given to the perpetuation of race, so that they can ultimately win the struggle. As a result, the reproductive mechanism has undergone extensive modifications. Perpetuation of race can be maintained either by the process of overproduction of eggs or by caring of a small number of eggs. Rearing or care of the offsprings is an achievement in the trends of evolution. It will be unwise to think that the care of youngs is a mammalian monopoly. Although it has taken a perfect shape in mammals, the phenomenon of parental care is quite well-developed in amphibians where extreme modifications in structure and behaviour are observed. Parental care is mostly a modification in the parents to take care of the offsprings so that with a meagre number of eggs continuation of race can be maintained.

Ways by which parental care is effected:

The parental care in Amphibia seems to have developed independently in the animal kingdom. There are various ways by which the parental care is manifested in amphibians.

Selection of site. Care of the eggs is restricted to the selection of site in certain frogs and toads. In *Rhacophorus schlegli* of Japan, the eggs are laid in a hole in a muddy bank of river or ponds. The eggs are covered by foamy mucus to prevent desiccation. The eggs are washed out into the water of the river or ponds by the rain and development starts there. In *Gyrinophilus*, the eggs are laid under the stones in stream. The eggs are then taken up at any part of the body and a secretion prevents growing of fungi over them. Eggs are laid under the surface of leaves hanging above water in *Hylodes*. In *Triton* and *Leptodactylus* the eggs are laid under the surface of leaves near the vicinity of water. In *Triton*, the eggs may be fixed with the aquatic weeds by glues. In hynobiid salamanders, the males remain with the eggs for fertilization and take active interest of the eggs.

Frothing of water. In *Rhacophorus maculatus* just after the laying of the eggs, the surrounding water is made frothy by the wriggling movement of hindlimbs, so that the eggs are prevented from desiccation and also can escape the sight of enemies. Both males and females participate in this process.

Formation of nests. After laying of eggs the parents take care of them by building nests. *Mud nest.* In *Hyla faber*, parents dig a small hole in the mud for the developing eggs and the surplus mud acts as the wall (Fig. 6.33A). *Leaf nest.* In *Phyllomedusa*, a South American tree-frog, the leaf nest is produced by folding the margin of the leaves. Leave-margins are glued together by cloacal secretion. It has an aperture at the base and the nest overhangs watery area. *Shoot nest. Triton* constructs shoot nest by fixing the shoots of the trees in which the eggs are deposited and the youngs are developed. The whole nest is covered by a gelatinous secretion.

Carrying the eggs over the body. In *Hyla goeldii*, the females carry the eggs on their back in incipient brood pouches. In midwife toad, *Alytes obstetricans* of Europe, the male helps the female to discharge the eggs by massaging the cloaca. After fertilization the eggs are wrapped round the back of the thigh and are carried from one place to

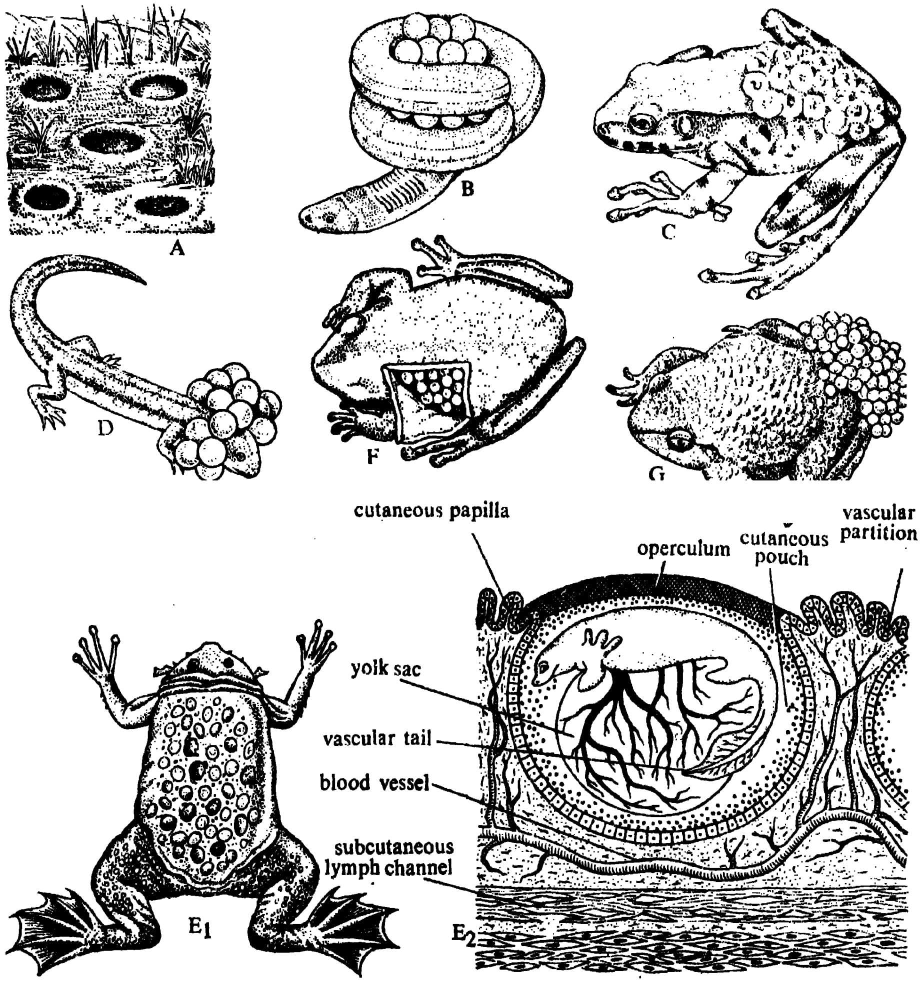


Fig. 6.33. Parental care in amphibians. A. Mud nests of *Hyla*. B. *Ichthyophis* coiling round the eggs. C. *Cryptobatrachus evansi*. The brood pouches are opened to show the developing eggs. D. *Desmognathu fuscus* with eggs. E$_1$. *Pipa pipa*. E$_2$. Pseudoplacentation in *Pipa dorsigera*. F. *Gastrotheca*. G. *Alytes*.

the other. (Fig. 6.33G). In *Desmognathus*, the females carry the eggs (Fig. 6.33B) and live in underground hole. In *Pipa pipa*, the eggs are carried by females on the back. Similar phenomenon is observed in *Cryptobatrachus evansi* (Fig. 6.33C). The soft spongy skin on the dorsal side sink into small pockets into which eggs are lodged (Fig. 6.33E$_1$). The same phenomenon is also observed in *Pipa dorsigera* where the eggs are deposited in pits on the back of females. During breeding season, the dorsal skin of the females becomes soft, spongy and gelatinous. The male places the eggs on the back of female where each egg sinks into a small pit. An operculum covers the pit. It is developed out of the remnant of the egg envelop and integumentary secretion. Development is completed inside the cutaneous pit. The partition between the pits becomes highly vascularised. The developing larva attains a vascular tail (Fig. 6.33E$_2$). Physiological exchange of materials between the embryonic and maternal tissues is claimed to occur in this animal. The larva fails to develop gills and the tadpole larva comes out after 80 days of the deposition of the egg. In *Nototrema* (= *Gastrotheca*) *pygmaeum* (Fig. 6.33F) only a few eggs develop in the brood pouch on the back of the female. Each pouch bears a small slit-like opening in the posterior side. In *Nototrema marsupiata*, the youngs hatched out as the tadpoles while in *N. oviferum* the metamorphosis is fully completed inside the brood pouch.

Carrying the larvae from one place to other. In *Arthroleptis* the larvae are attached to the males and are carried from one pond to the other. At the time of danger they are kept inside the buccal cavity.

Placement of the eggs in safest part. In oviparous caecilians as examplified by *Ichthyophis* the body remains coiled round the egg mass to guard them until hatching (Fig. 6.33B). But in ovoviparous caecilian, *Geotrypetes* the eggs are yolky and migrate to the last part of the oviducts. When the yolk is exhausted and the external gills atrophied, the embryos, about 25 mm long, hatch and remain inside the oviducts till the embryos become 75 mm in length. The developing youngs get nutrition from the uterine 'milk'. Metabolic exchanges also occur between the vascular maternal and featal tissues. In *Rhinoderma darwini*, the eggs are swallowed by the males and are placed inside the inflated vocal sac where the eggs may remain there uptil hatching or even upto the completion of metamorphosis.

Viviparity. Extreme modification is observed in *Salamandra atra* and *S. maculosa*. The eggs are placed inside the uterine cavity where entire tadpolehood is completed. Two eggs are laid at a time. The larvae are attached with the uterine wall by membrane which functions physiologically in the manner of a primitive placenta. The broad and vascular tail also helps in metabolic exchanges.

The foregoing description reveals some of the ways by which parental care is effected in different amphibians. The question now is whether this phenomenon of parental care in amphibians has any parallelism with that observed in mammals. Experimental evidences on this particular issue is meagre to establish the actual controlling mechanism. It is certain that the care of the youngs in amphibians evolved probably in response to their habit and the environment they live. Two alternate explanations can be forwarded. These are: (1) The care of youngs by the parents is largely behavioural and mechanical in nature which may be influenced by the hormonic actions. (2) The care of youngs is either instinctive or due to the reflex action developing during the breeding season. This contention seems more convincing. The care of eggs or youngs is largely, if not, purely instinctive in nature rather than anything else.

ORIGIN OF AMPHIBIA

During the middle of Devonian time, the bony fishes had differentiated into the actinopterygians on one hand and into the dipnoans and crossopterygians on the other. The climax of evolution was reached when the descendents of some crossopterygians left the water and invaded the land. This event of transition from the water to land ushered in a new phase in vertebrate evolution, the beginning of the land vertebrates. The amphibians started the beginning of tetrapod history. By invading a new environment on land, the amphibians opened broad avenues for further evolution over a wide range of structural and functional adaptations. Before going into the discussion on the ancestry of the amphibians, the steps the first amphibians have taken to meet the basic requirements for life on land are described below:

(1) The amphibians have developed two pairs of limbs. These are well-equipped with adequate muscles and strong girdles to lift the body away from the frictional contact of the ground. The carrying of the weight of body on the four limbs has caused great change in the vertebral column. The vertebral column loses flexibility to give rigidity.

(2) The problems of breathing in air are solved by developing well-formed lungs for gaseous exchange in air. The moist skin in modern amphibians also acts as an accessory respiratory organ.

(3) All amphibians possess well-developed vascular system, a new scheme for the development of lungs, i.e., introduction of pulmonary circuit. This has caused tremendous change in the structure of the heart and the circulatory system as a whole.

(4) Development of a middle ear cavity with a bone to transmit the vibrations from tympanum to inner ear helps in the intensification of the sound waves of air.

(5) The skin becomes suited for terrestrial life to resist desiccation.

Search of ancestry

The modern teleosts, as already discussed, have reached the peak of evolutionary success amongst the primary water-living vertebrates. They have undergone extensive adaptive radiation. The breathing fishes, the dipnoans and the crossopterygians exhibit a close relationship with the amphibians and it is an apparent biological truth that a group of such lung-fishes gave rise to the new terrestrial population—the amphibians. So the chance for dipnoans and crossopterygians to hold the significant position in amphibian ancestry needs consideration. How did the early amphibians meet the new requirements imposed upon them as a result of change from an aquatic to terrestrial life is to be solved first. The early amphibians must have fulfilled the basic requirements for living on land by making the following modifications: (1) Partial loss of armours although present in some earliest amphibia, e.g., Stegocephalians. (2) Loss of unpaired fins. (3) Development of terrestrial appendages by transforming the paired fins into limbs. (4) Loss of internal gills and acquisition of lungs.

Dipnoi—foreshadowed amphibian organisation. It was a general belief that the dipnoans stand in the direct line of tetrapod descent, because the dipnoans show many structural and functional resemblances with the amphibians. Although the pectoral and pelvic girdles in dipnoans cannot support the weight of the body on land, these girdles foreshadowed some amphibian features in several ways. These are: (1) The internal skeleton of the paired appendages is well-developed in dipnoans. (2) Paired appendages articulate with the respective girdles by a single proximal bony piece, which can be compared with the humerus or femur. (3) Outward extension of myomeric muscles into the paired fins is quite suggestive of the arrangement of musculature of the paired appendages of Amphibia. (4) Ability to breathe air by lungs (modified swim-bladder). (5) Pectoral girdle of *Necturus* resembles closely that of dipnoans. Although the dipnoans present some specialisations towards a method of living out of water, the total evidences direct quite clearly to the fact that they are not on the direct line of emergence of amphibia from fishes. The dipnoans exhibit too many specialised features and such a specialised group cannot hold the ancestry of another group of animals. Striking similarities, especially in circulatory and respiratory systems, are possibly due to the physiological convergence for living in similar condition of life. The dipnoans, today, give an idea of the form that probably linked the fishes with the amphibians. The dipnoans are usually regarded as the collateral uncle of the amphibia.

Crossopterygians—direct the channel of amphibian evolution. To trace the direct line of amphibian origin from the fishes, the importance of the crossopterygians in holding the probable starting point needs consideration. The early crossopterygians, as examplified by the Devonian genera, *Osteolepis* and *Eusthenopteron* furnish the strongest support. Because they possess many features which are certainly amphibian or lead towards amphibia. The features are: (1) Bony pattern of jaws and skull are comparable to that observed in early amphibians. (2) Two large bones on the top of skull can be homologised as the amphibian parietal bones. (3) Pectoral girdle presents certain features which are prerequisites for amphibian forelimbs. (4) Skull of Eusthenopteron contains almost all the elements observed in the early amphibians. (5) Pectoral fin of Eusthenopteron can be compared to the forelimbs of amphibia. The single proximal piece of bone can be homologised with the humerus and the next two pieces can be compared to radius and ulna. (6) Various wrist and ankle bones, the bony elements of hand and foot have evolved from the distal bony complex of the crossopterygian fins. Thus, in many respects, the crossopterygians show close similarities with the amphibians and it is expected that these fishes are the direct progenitors of the early amphibians. The most dramatic event to note in amphibian evolution is the transformation of the crossopterygian paddles into amphibian limbs. The sequences how the amphibian limbs arose from a fish fin is a controversial issue. It is probable that the lobed fins of crossopterygians specially seen in Eusthenopteron have become transformed into the tetrapod limbs. As the fish came on the land, the paired appendages perhaps first carried only the weight of the body and the muscles of the appendages became capable of only forward and backward movements. With the evolution of the tetrapods on land, the limbs became elongated and shifted under the body to raise the body further away from the ground. While on land the muscles became modified and arranged around the

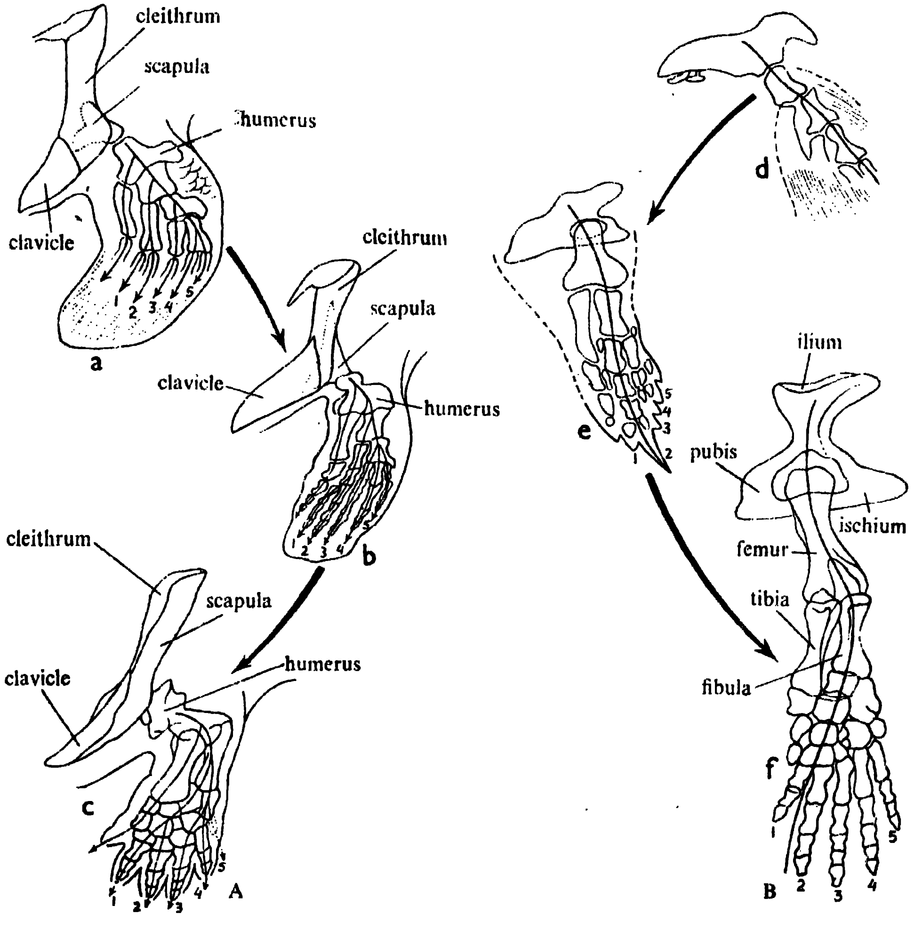


Fig. 6.34. Schematic diagrams of the supposed transformation of crossopterygian pectoral and pelvic girdles and fins into the corresponding appendicular structures of amphibians (after Young). A. Crossopterygian pectoral girdle and fin. (*a*) *Eusthenopteron*. (*b*) *Eogyrius*. (*c*) *Eryops*. **B.** Crossopterygian pelvic girdle and fin. (*d*) Hypothetical stage. (*e*) *Eusthenopteron*. (*f*) *Trematops*.

shoulder and hip joints for balanced movement on land. For the attachment of the muscles the girdle became expanded into plates consisting of different characteristic pieces. The shoulder girdle of an earliest amphibia, *Eogyrius* inherited a shoulder girdle closely similar to the Osteolepis. Fig. 6.34 gives an idea of the possible stages of transformation of the crossopterygian girdles and fins into the tetrapod girdles and limbs respectively. The actual and documentary transitional limb is still unknown. But the most ancient footprint of *Thinopus* throws much light on the process of transformation.

Factors that caused amphibian Evolution. What were the factors that led the Crossopterygians to leave their primal aquatic home and to come to land? Romer suggested that it was the desire for more water that caused the first excursion of crossopterygians from one place to other. Berrill is inclined to think that the enemies in the water forced the crossopterygians to leave for land. Other factors are the abundance of food in land, lure of atmospheric oxygen and recurrence of unfavourable environment. It seems that the real cause is neither safety nor food nor the desire to breathe atmospheric air, but an adaptation which has been imposed repeatedly upon the crossopterygians by recurrence of hostile environment. Most probably, during late Devonian period, due to excessive periodic drought, crossopterygians were forced to search for new fresh water streams and lakes, where they can live and thus escape the risk of survival. By this way they had to cross dry land to find suitable water. From such a start the amphibians evolved in the geological age and became adapted to the new terrestrial environment.

Probable ancestry During the Devonian time, some of the crossopterygians came out on land. This group was probably the rhizodonts being represented by the *Osteolepis* and *Eusthenopteron*. It was a very significant step to come into a completely new environment. On coming to land these advanced air-breathing fishes became transformed into primitive amphibians. Figure 6.35 shows the phylogenetic tree of the amphibians. *Ichthyostega* exhibited a transitional phase by possessing an admixture of piscine and amphibian characters. Ichthyostega, although retained many distinct piscine characters, has paved the path of amphibian evolution.

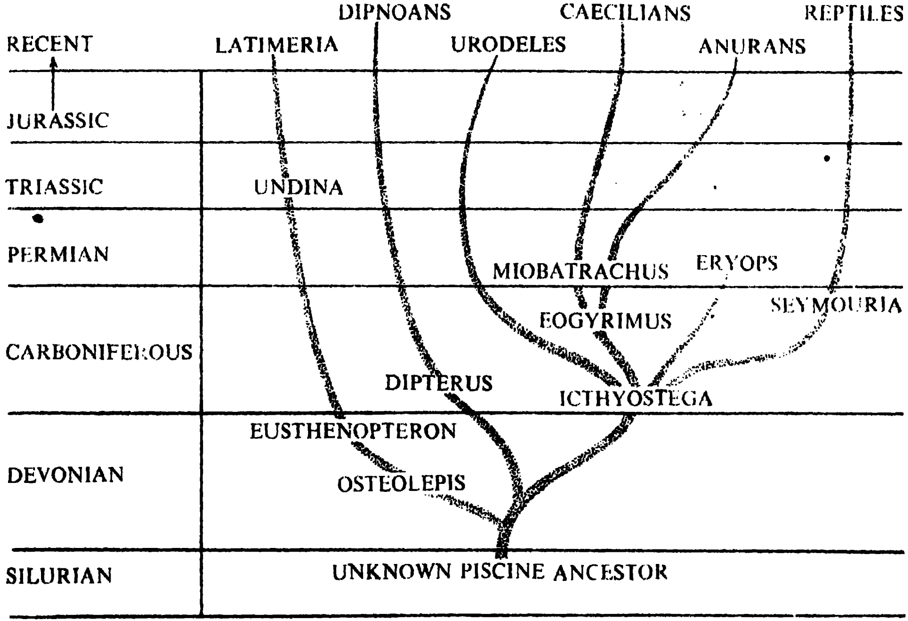


Fig. 6.35. Probable phylogenetic tree of the amphibians.

SUMMARY

(1) The amphibians were the pioneers amongst the tetrapods in the phylogenetic history of the vertebrates. They constitute a special class of back-boned animals that invaded a new environment on land from water where their progenitors lived for millions of years. They were the descendents of some crossopterygian fishes of the Devonian period.

(2) While coming on land, the amphibians underwent tremendous biological changes to become land-living animals. Such evolutionary development was necessary for the change from an aquatic to terrestrial mode of life.

(3) The amphibians, as we see today, are capable of respiration on land by lungs but their larvae breathe in water by gills. The acquisition of lungs has caused great change in the circulatory system. The skin is also modified to prevent drying-up or desiccation on land. In modern amphibians, the skin is kept moist, highly vascular and subserves respiration both in water and on land.

(4) The axial and appendicular skeletal framework becomes greatly altered to a new method of locomotion on land. The vertebral column becomes rigid and the paired appendages with the corresponding girdles become specialised to lift the body off the ground. The skeleton of the limbs together with the muscles help the animals to propel across land effectively.

(5) The amphibians have completely failed to solve the problem of reproduction on land. As a consequence, all the animals under this class have been forced to go back to their primal aquatic home for laying their eggs and subsequent development of the youngs.

(6) Class Amphibia is divided into three extinct and three living orders. The extinct orders are: *Labyrinthodontia*, *Phyllospondyli* and *Lepospondyli*. The living orders are: *Gymnophiona*, *Urodela* and *Salientia*.

(7) Order *Gymnophiona* includes the degenerated snake-like caecilians. Order *Salientia* embraces the frogs and toads. They are the highly specialised forms amongst the amphibians. Order *Urodela* is a more primitive group than the anurans. Many of them have retained larval characteristics and thus exhibit paedogenesis or neoteny.

(8) The amphibians present great diversity in forms due to their adaptations to different environments. The study of the life and structure of *Bufo* will give a general idea of the biology of the class as a whole.

(9) In majority of the amphibians, the ontogenetic developmental history is accompanied by progressive metamorphosis.

(10) The phenomenon of caring of the eggs or developing youngs is well-developed in many amphibians where extreme structural and behavioural modifications are encountered.

CHAPTER 7

Phylum Chordata—REPTILES

Reptiles are the true land vertebrates that gave up the practice to go back to water to lay eggs. "Things that before swam in the water now went upon the ground" goes the saying. In fact the emergence of reptiles as the true land dwelling vertebrates offer the greatest dramatic event in the course of organic evolution. Emerging from the old aquatic environment, the reptiles became successfully adapted to the new regime and as a result evolution within themselves became escalated. The reptiles dominated the globe in their early phase of evolutionary history and are represented today by a few divergent specialised forms (Fig. 7.1).

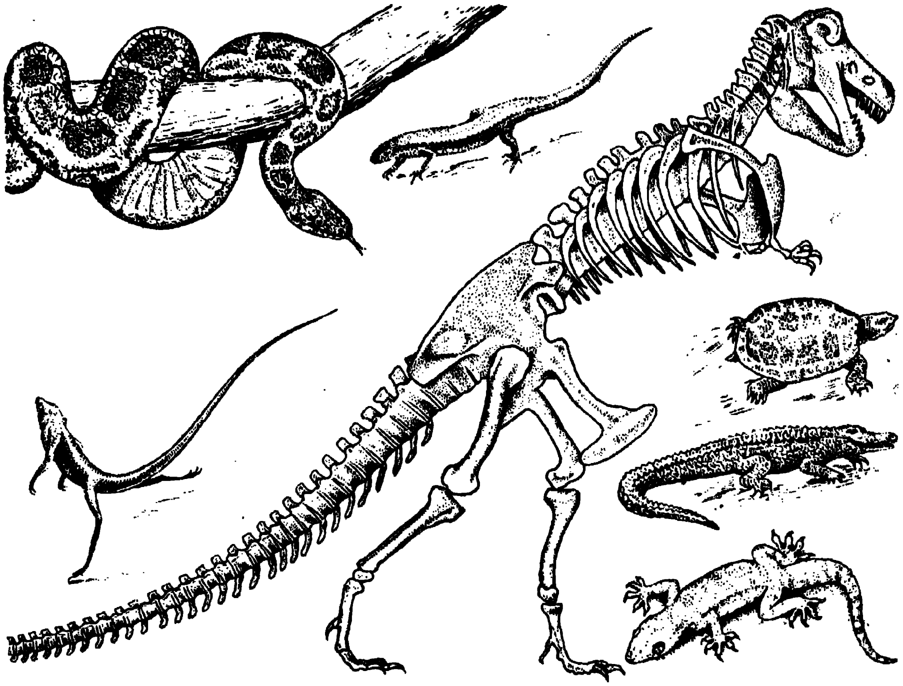


Fig. 7.1. Showing the skeleton of a prehistoric reptile and some living members of the class Reptilia.

IMPORTANT FEATURES

Reptiles form a great central assemblage of plastic forms that tried to master most of the available environments though they are primarily terrestrial. They show (1) bilateral symmetry and possess paired pentadactylous limbs which end in digits (except snakes). The digits end in claws. (2) A post anal tail is usually present. (3) The cloacal aperture is usually transverse. (4) The body temperature of the reptiles is not constant. They are cold-blooded or poikilothermal vertebrates. (5) The body is covered by epidermal scales plates are present. (6) The salivary glands in reptiles are few in number. (7) The coelic caecum is associated with the rectum in most cases. (8) Reptiles are wholly lung breathers. (9) The heart of the reptiles consists of a sinus venosus, two auricles and a ventricle which is incompletely divided by a vertical septum (complete in crocodiles). Conus arteriosus is absent. They have both the left and right systemic arches. Ductus caroticus and ductus arteriosus are often present. (10) The kidney in reptiles is of metanephric type. An allantoic urinary bladder is present. (11) The sexes of reptiles are separate. Males possess intromittent organs. (12) Most reptiles are oviparous and viviparity is present in some snakes. The eggs are large, yolky and shelled. (13) The embryos of reptiles are provided with amnion and allantois. (14) The reptilian brain is well-developed and has both commissures and connectives. Presence of aberrant commissure is a dignostic feature of reptilian brain. (15) Sense organs are well formed and organ of Jacobson is present.

OUTLINE CLASSIFICATION

Class Reptilia includes a heterogeneous group of land vertebrates. They are classified into five subclasses. The subclasses are: Anapsida, Ichthyopterygia, Lepidosauria, Archosauria and Synapsida. These subclasses are divided into many orders. The members of the orders are mostly extinct excepting the representatives of the orders: *Squamata* (e.g., Lizards and snakes), *Rhynchocephalia* (e.g., *Sphenodon*), *Chelonia* (e.g., Tortoises and Turtles) and *Crocodilia* (e.g., Crocodiles, Gharials, Alligators and Caimans).

Example of Reptilia—CALOTES

Calotes versicolor is a common Indian garden lizard. It is often called a blood sucker but in reality it does not suck blood. The colour of the body is changeable and in males the head is often blushed red.

HABIT AND HABITAT

Calotes passes much of its time lying on boughs and twigs. It is often seen running swiftly on ground. It can swim, if necessary. Calotes lays its eggs in holes in the ground. It is widely distributed in India and southern China.

EXTERNAL STRUCTURES

The body of Calotes is divisible into three regions-*head*, *trunk* and *tail* (Fig. 7.2A). A small narrow neck joins the head with the trunk. The head is more or less triangular in appearance. The *snout* is short, pointed and bears a pair of apertures called the *external nares*. The eyes are provided with movable *nictitating membrane*. The mouth is a transverse aperture. It is terminal in position and lips are absent. The *tympanum* is situated behind the eyes. The trunk is elongated, subcylindrical and bears two pairs of appendages, the *forelimbs* and *hindlimbs*. The forelimb is divisible into *brachium*, *antibrachium* and *manus*. Likewise the hindlimb is divisible into *femur*, *crus* and *pes*. The limbs end in *digits* and the digits are with sharply pointed claws. The *cloacal aperture* or *vent* is a transverse opening and is

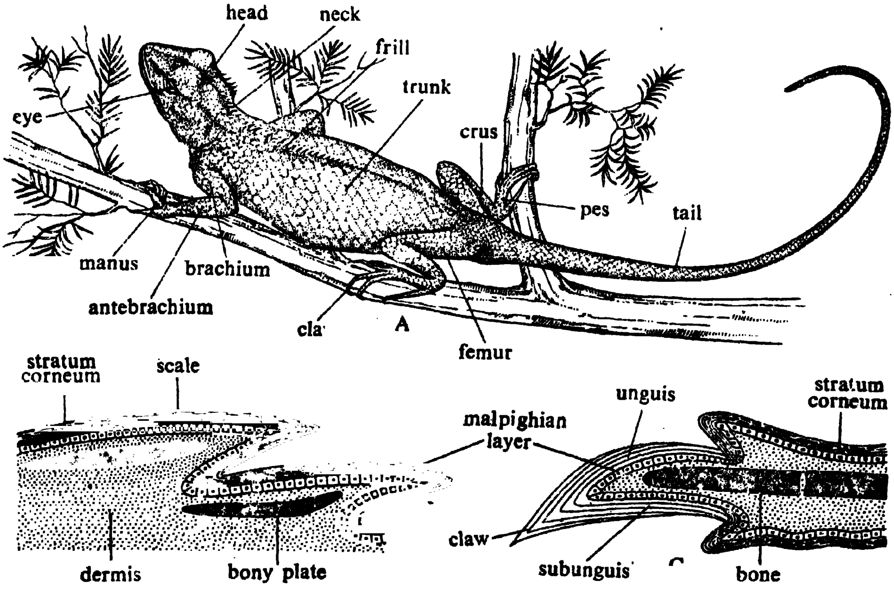


Fig. 7.2. A. External structures of *Calotes*. B. Sectional view of the skin showing the disposition of scales of *Calotes*. C. Sectional view of a claw of *Calotes*.

situated in the posterior-ventral part of the trunk and at the base of the tail. A large *cloacal plate* is situated in front of the cloacal aperture. The tail is long, slender and tapering. It measures twice as long as the head and body. Males measure 120–140 mm from snout to vent with a tail of 300–500 mm. The body length of females is less by 15–20 mm.

The colour of the body is brown or greyish on the dorsal surface and dirty whitish ventrally. The dorsal surface may be uniform in colour or may have dark brown transverse spots or bars. Dark streaks radiate from the eye region. Young females often show two light yellow dorsolateral stripes. Fully grown males have greenish tinge. The tail exhibits alternate dark and light annuli.

Calotes, like many lizards such as chameleons, possesses a peculiar power of changing the colour of skin. Change in colour is due to the contraction or expansion of *chromatophores* (pigment cells) which are possibly under nervous control. The colour is a protective device and serves in protecting the animal from the enemies.

SKIN

The skin of Calotes is highly modified for living on land. To safeguard the animal against the frictional contact with the dry ground as well as to prevent desiccation in dry air, the epidermis becomes greatly elaborated than the dermis. The skin glands, so common in amphibians, are totally absent. The absence of skin glands and acquisition of scales over the body are evolutionary achievements for living on dry land.

The epidermis is a compound layer which is composed of an inner layer of columnar cells called the *stratum germinativum* (or *Malpighian layer*) which is arranged on a *basement membrane*. The outermost layer of epidermis is represented by a dead *stratum corneum*. Between the stratum corneum and the stratum germinativum lie the transitional layers. The stratum corneum becomes thickened over the scales, while between the scales this layer becomes thinner.

SKELETAL STRUCTURES

Calotes has well-developed framework of bony endoskeleton and definitive exoskeletal structures outside the body.

Exoskeleton

Being a terrestrial animal, Calotes possesses well-developed exoskeletal structures. The body is covered by a nonconducting coat of scales.

Scales

The scales are epidermal in origin and are arranged in an imbricate fashion. The ventral scales are smaller in size than the dorsal ones. The scales develop from the stratum germinativum (or Malpighian layer) of the epidermis. These are plate-like structures, each is supported by a bony plate or ossicle (Fig. 7.2B) in the dermis. On the dorsal side, the postaxial scales are larger than the preaxial scales. The scales on the head region are large and do not overlap but unite each other by their edges. These larger scales are called the *head shields*. Few scales situated on the middorsal line and the border line of neck have become modified into large and pointed structures. These are capable of movement and are usually called the "*frills*". Similar structures are also present on the postero-lateral border of the head.

Claws

The digital tips of Calotes are provided with sharp claws. Each claw is made up of a dorsal and a ventral scale like horny plates. These plates are so placed that they converge at the end of the digit to make the tip pointed. The dorsal plate is called the *unguis*. It is convex and rounded at tip and lateral sides. The ventral plate is called the *subunguis*. The subunguis is flattened (Fig. 7.2C). The plates are derived from the Malpighian layer of the epidermis. The unguis is well-developed than subunguis.

Endoskeleton

The hard skeletal parts present inside the body (endoskeleton) are grouped into axial and appendicular divisions. The axial skeleton includes the skull and vertebral column while appendicular skeleton includes the girdles and limb bones.

SKULL. The skull of Calotes is well ossified but cartilaginous elements persist in the region of nares and interorbital septum. The brain box (or cranium) is comparatively small and is covered by investing bones.

The roof of the skull is made up of a pair of *parietals* which are fused and bear a median parietal foramen, a pair of *frontals* and two *nasal bones* (Fig. 7.3A). The *premaxillae* are situated anterior to and between the nasals while the sickle-shaped *squamosals* are attached to the posterolateral sides of the parietals by sutures. On the roof of the orbit there are many small bones, of which the anterior and posterior ones are known as *prefrontal* and *postfrontal* respectively. The floor of the skull is composed of a flat and large *basal bone* formed by the fusion of occipital and sphenoidal elements. The basal bone continues forward as a slender bar and is called *parasphenoid* (Fig. 7.3B). From the basal bone arises a pair of stout *basipterygoid processes.* These processes articulate with the *pterygoid.* The pterygoid forms a bridge between the quadrate (posteriorly) and palatine (anteriorly). From the junction of pterygoid and palatine arises a stout *os transversum* or *transpalatine process* which extends to join the *maxilla.* The *vomer* is small, anterior to palatine and articulates with premaxilla and maxilla. The premaxillae and maxillae are furnished with small teeth.

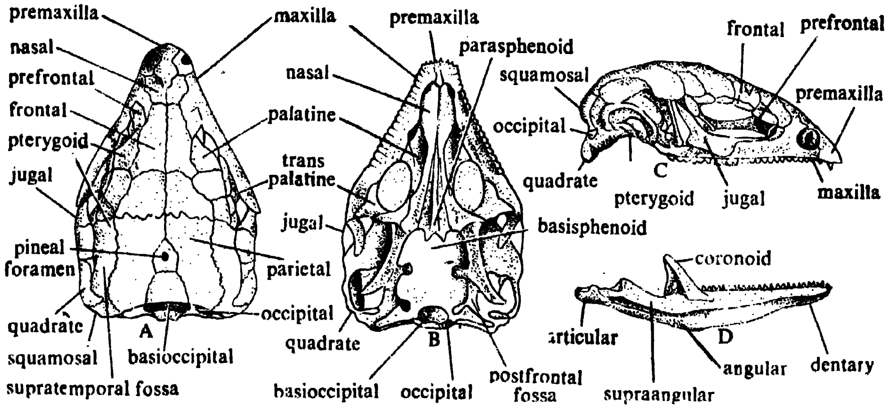

premaxilla
nasal
prefrontal
frontal
pterygoid
jugal
pineal foramen
quadrate
A
squamosal
basioccipital
supratemporal fossa
maxilla
nasal
palatine
trans palatine
jugal
parietal
occipital
quadrate
premaxilla
parasphenoid
B
basioccipital
occipital
postfrontal fossa
squamosal
occipital
quadrate
basisphenoid
frontal
prefrontal
premaxilla
C
pterygoid
jugal
maxilla
coronoid
articular
D
angular
dentary
supraangular

Fig. 7.3. Dorsal (A), Ventral (B) and Lateral (C) view of the skull of *Calotes.* D. Lower jaw of *Calotes.*

The posterior part of the skull is made up of large *exoccipitals* which are continuous with the horizontal *prootic processes.* The *foramen magnum* is an aperture situated between the occipitals. There is a single *occipital condyle.* The lateral wall of the cranium is mainly formed by a paired prootics. The *epipterygoid* (or *columella*) is extended from the prootic to the pterygoid. The jugal bones border the lateral and posterior limits of the orbit (Fig. 7.3C). The quadratojugal is not ossified.

The *lower jaw* is composed of two similar halves (or *rami*). Each *ramus,* in addition to the slender persistent *Meckel's cartilage,* consists of six pieces of investing bones which fuse with each other. The names of the six bones are: *articular, angular, supra-angular, coronoid, splenial* and *dentary.* Of the bones, the dentary has the mandibular teeth (Fig. 7.3D). The two rami are sutured to one another in front. The lower jaw is articulated to the cranium through the quadrate which is movable and such attachment of lower jaw is *streptostylic* in nature. The lower jaw bears teeth.

VERTEBRAL COLUMN. The vertebral column consists of vertebrae which are divisible into the following regions: (*a*) Cervical region—composed of 8–10 vertebrae, (*b*) Thoracolumbar region—made up of 22 vertebrae, (*c*) Sacral region—containing only two vertebrae and (*d*) Caudal region—consisting of about 20 vertebrae. All vertebrae, excepting the first and the last, are strongly *procoelous.*

Cervical vertebrae. The first cervical vertebra is known as the *atlas* (Fig. 7.4A). It is ring-like having a single articular facet. The *centrum* is absent. The *neural arch* is incomplete dorsally and transverse processes are ill developed. The second cervical vertebra is called the *axis* (Fig. 7.4C). It bears a small peg-like process called the *odontoid process* at its anterior face. The odontoid process actually represents the centrum of the atlas. The midventral line of the axis is provided with a ridge called *hypapophysis.* The rest of the cervical vertebrae are typical but bear cervical ribs. The atlas and axis do not bear ribs.

Thoracic vertebrae. The thoracic vertebrae are typical in nature (Fig. 7.4B,D). The hypapophysis is ill-developed or absent. All the vertebrae bear *thoracic ribs.* Only five anterior thoracic ribs reach the *sternum.*

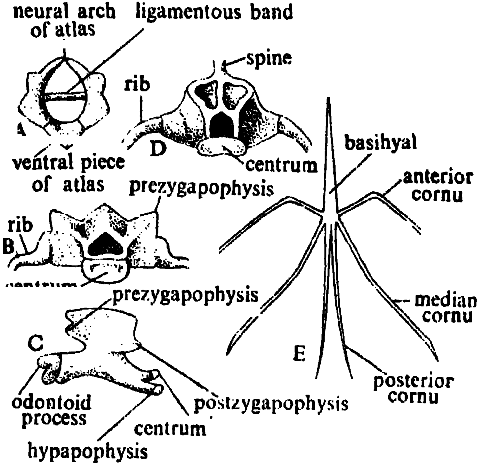


Fig. 7.4. Vertebrae and hyoid apparatus of *Calotes.* A. First vertebra (anterior view). C. Second vertebra (lateral view). B. Typical thoracic vertebra (anterior view). D. Typical thoracic vertebra (posterior view). E. Hyoid apparatus.

Sacral vertebrae. The two large sacral vertebrae bear large and expanded ribs.

Caudal vertebrae. The ventral surface of the caudal vertebrae are provided with 'Y'-shaped *chevron bones.*

STERNUM. The sternum (or breast bone) is a rhomboidal plate-like structure and ventral in position. The sternum is supported by a characteristic 'T'-shaped *interclavicle* and it bears an aperture called *sternal aperture* at its middle. The sternum bears ribs. The plate-like sternum protects the internal organs.

HYOID APPARATUS

The floor of the buccal cavity is supported by a cartilaginous structure called the *hyoid apparatus* (Fig. 7.4E). It also supports the tongue. The hyoid apparatus consists of the *basihyal, anterior cornua, middle cornua* and *posterior cornua.* The basihyal constitutes the body proper of the hyoid apparatus. It is a median cartilaginous rod and directed anteroposteriorly to form the *os entoglossus.* The anterior cornua are elongated cartilaginous rods and arise anterolaterally from the basihyal. These rods curve round the oesophagus and terminate near the ventral side of the auditory capsule. The anterior cornua represent the hyoidean arch. The middle cornua are ossified at their proximal ends and represent the vestiges of the first branchial arches. The posterior cornua arise from the posterolateral edge of the basihyal. They extend backwards and outwards. Each cartilaginous rod is composed of two segments.

Appendicular skeleton

The skeleton of the paired limbs and girdles constitute the appendicular skeleton.

Pectoral Girdle. The pectoral girdle is hoof-shaped and composed of two symmetrical halves. It is situated in the thoracic region of the body being attached to the vertebral column by means of muscles and ligaments. Each half of the girdle is made up of a partially cartilaginous *scapula.* The scapula is dorsolaterally extended (Fig. 7.5A). The suprascapula is a bony plate-like structure and is attached to the scapula. It is ventrolateral in position. The *coracoid* is also plate-like and is made up of cartilaginous *epicoracoid* and *precoracoid.* The *glenoid cavity* is formed by the scapula and coracoid. The *clavicle* is a narrow curved bone and forms a bridge between interclavicular junction and scapula. The two halves of the girdle are attached to a rhomboidal and plate-like *sternum* which is ventral in position. The sternum is supported by a 'T'-shaped *episternum* (or *interclavicle*). The sternum bears *ribs* and a centrally placed *sternal foramen* through which the sternal artery passes. The 'T'-shaped interclavicle, sternal ribs and sternal foramen are diagnostic features of the reptilian pectoral girdle.

Pelvic girdle. The pelvic girdle is also made up of two equal halves. Each half is called the *os innominatum* which is composed of the *pubis, ischium* and *ilium* (Fig. 7.5B). These three bones are attached in a triradiate fashion. The two halves of the girdle are attached with each other through the intermediation of pubis and ischium. Hence the joining is called the *ischiopubic symphysis.* The pubis bears an *epipubic* cartilage at its tip and a pubic prominence as a projection at the other tip. The articulation facet, *acetabulum* is situated close to the pubic prominence. Between the two ischia there lies the hypoischiatic cartilage. The *obturator foramen* is incomplete.

Forelimb. The forelimb consists of the following long bones arranged in order from proximal to distal end (Fig. 7.5C). *Humerus*. It is a slender and slightly curved bone which bears swellings (or condyles) at the proximal end. This swelling is called the *head of humerus*. The distal end bears a pully-like *trochlea*. Spherical epiphysis is associated with both ends. The *deltoid ridge* is absent.

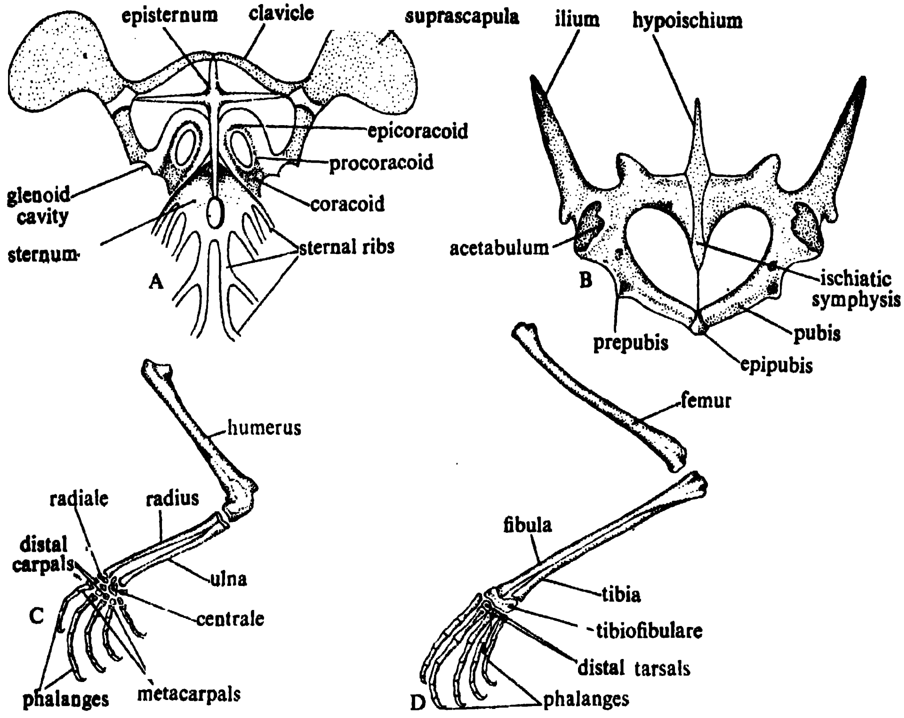

episternum
clavicle
suprascapula
ilium
hypoischium
epicoracoid
procoracoid
glenoid cavity
coracoid
sternum
sternal ribs
acetabulum
A
B
ischiatic symphysis
prepubis
pubis
epipubis
femur
humerus
radiale
radius
distal carpals
ulna
fibula
C
centrale
tibia
tibiofibulare
distal tarsals
phalanges
metacarpals
D
phalanges

Fig. 7.5. Appendicular skeletons of *Calotes*. A. Pectoral girdle. B. Pelvic girdle. C. Forelimb bones. D. Hindlimb bones.

The antibrachium is supported by *radius* and *ulna*. These two bones are narrow, elongated and are distinct from each other. The radius is preaxial in position and its distal end is produced into a process called the *styloid process* while the anterior terminal end of ulna is produced into a short process called the *olecranon process*. The radius and ulna are articulated with the humerus through their anterior concavities. In the manus, there are ten pieces of *carpal bones*. The carpal bones are cubical in shape and are arranged in two rows. The proximal row consists of a large central piece called *centrale*, one piece each beneath radius and ulna are called *radiale* and *ulnare* respectively while the third and ofurth pieces are fused together to form the *intermediate*. The distal row of carpals do not show structural variation. An extra piece of bone developed preaxially between ulna and ulnare is present. This bone is called *pisiforme*. This is a sesamoid bone (or tendon bone) and its presence is very unusual. Five narrow but cylindrical *metacarpals* form the palm. The five phalanges are provided with claws and the bones in phalanges number 2, 3, 4, 5 and 3 from 1st to the 5th.

Hindlimb. The hindlimb consists of a stout and enlongated *femur* which is provided with epiphysis at both the ends. The anterior end of the femur is round while posterior end bears two ball-shaped condyles. Above the outer condyle, there is an elevated portion which gives attachment to the next pieces of bone. The anterior side of femur is provided with a rough surfaced *trochanter* to which muscles remain attached. The shank is composed of tibia and fibula (Fig. 7.5D). The tibia is preaxial in position. It is straight and stouter than fibula. The tibia bears a *cnemial crest* at its anterior surface and a concavity at its posterior part for articulation. The fibula is slender and bears a single concavity through which it articulates with the elevated portion of femur. The distal ends of both tibia and fibula are flat. In tarsal region, the bones are fused. A single large piece called *tibiofibulare* and two or three bones on the distal region are only identifiable. The foot is supported by five cylindrical and elongated *metatarsal* bones. Of these bones, two articulate with tibiofibula and the rest three with the distal tarsal bones. The digits are similar in structure to that of the forelimbs.

DIGESTIVE SYSTEM

The digestive system of Calotes is composed of the alimentary canal and digestive glands (Fig. 7.6A).

Alimentary canal. The alimentary canal starts from the *mouth*. The mouth is a transverse terminal aperture provided with teeth on jaws. The teeth are sharp, small, pointed and recurved backwards. All the teeth are similar in size and shape, i.e., *homodont* and the attachment is *pleurodont* in nature (Fig. 7.6B). The mouth leads into the *buccal cavity* which is large and compressed dorsoventrally. At the posterior part of the roof of buccal cavity, there are two openings for the *internal nares*. The floor of the cavity houses a median and muscular *tongue*. The tongue is protrusible and the apex of the tongue is bifurcated. The buccal cavity passes to the stomach through *pharynx* and *oesophagus*.

The *stomach* is elongated, sac-like and placed more or less vertically. The stomach is divisible into a cardiac and a pyloric portion. The pyloric part of the stomach is followed by *small intestine* which is narrow, tubular and coiled. The small intestine may again be divided into a 'U'-shaped *duodenum* and a long much coiled *ileum*. The small intestine is followed by a *large intestine* (or *rectum*) which is small, sac-like and opens into the *cloaca*. At the junction of ileum and rectum a small projection called *coelic caecum* is present. The colon is absent. The cloaca opens to the exterior by the anus (or vent). The whole of the alimentary canal is kept in position by folds of peritoneum. The stomach is attached with the body wall by the *mesogaster*, the ileum by the *mesentery* and the rectum by the *mesorectum*.

Digestive glands. Small unicellular *salivary* and *mucous glands* are present in the buccal cavity. These glands are few in

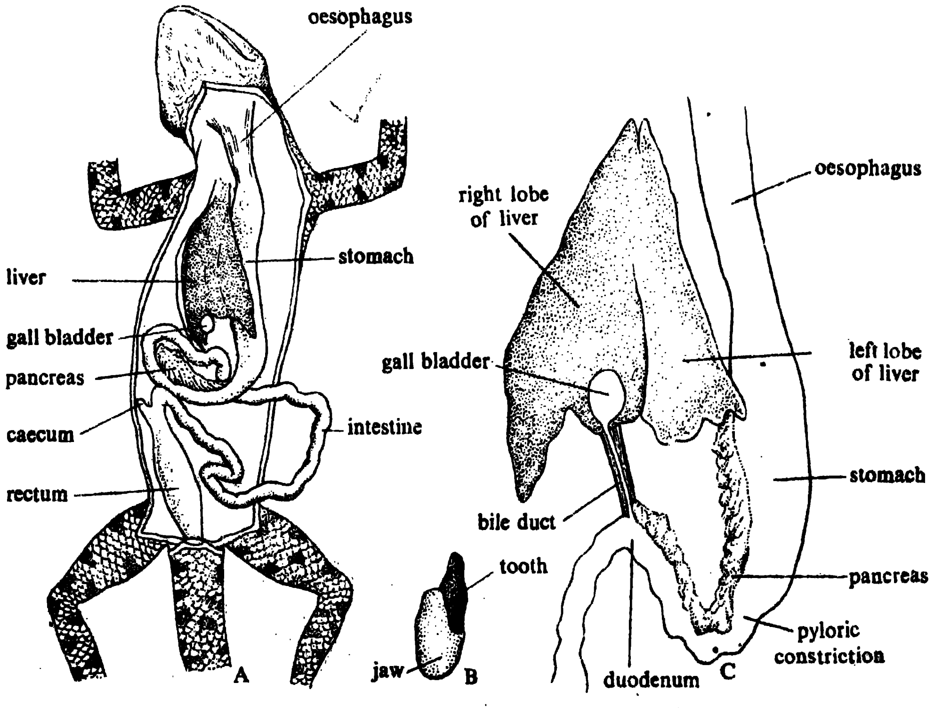


Fig. 7.6. A. Digestive system of *Calotes*. B. A tooth. C. Showing the structural relationship of liver and pancreas with duodenum.

number. The most important of the digestive glands is the *liver* which is massive and situated dorsal to the stomach. The liver is divided into left and right lobes. Both the lobes are united anteriorly (Fig. 7.6C). The liver secretes bile. The bile remains stored in the *gall bladder*. The gall bladder is a small and roundish sac which is situated on the outer margin of the right lobe of liver. The gall bladder is not provided with any duct and it is a reservoir of bile. The inner wall of the stomach is beset with large number of unicellular *parietal glands* and *gastric glands* which secrete hydrochloric acid and digestive enzymes respectively. Another important digestive gland is the *pancreas*. It is a flat and elongated structure. The colour is white. It opens into the beginning of the duodenum. The secretion of pancreas is called pancreatic juice. The juice is alkaline in nature and contains digestive enzymes. These enzymes are trypsin, amylopsin and lipase. The spleen is a small rounded glandular structure situated in the mesentery below the stomach. It is morphologically connected with the digestive tract, but has got no digestive role. The spleen stores the erythrocytes and also destroy them, when necessary.

Mechanism of foodgetting and digestion. The food of Calotes is mainly small living insects. Ingestion is done with the help of the tip of the tongue and the insect is taken inside alive. The sticky mucus secretion helps to catch the prey.

True digestion occurs in the stomach where HCl and pepsin reacts on the food matter. HCl makes the medium acidic and kills bacteria while pepsin reacts with the protein part of the food and breaks it into peptone and proteoses. In the next phase, digestion occurs in the duodenum. In the duodenum bile neutralises the acidic half digested chyme and emulsies the fat part of the food. Now pancreatic juice comes into play. Being alkaline in nature it makes the medium strongly alkaline. Digestive enzyme, trypsin (present in pancreatic juice) reacts with protein and proteoses and convert them into soluble amino acids. Amylopsin reacts with carbohydrate and gives glucose and lipase reacts on fat converting it to fatty acid and glycerol.

The mixture of food containing simpler and soluble products and undigested food materials passes into the intestine. The lining cells of the intestine take up the soluble products while undigested food particles are stored in the rectum from where these are voided periodically.

RESPIRATORY SYSTEM

Calotes is a true lung breather. Structurally the respiratory organs do not show any great improvement over the amphibians but functionally the lungs have become more efficient.

Respiratory structures. The respiratory structures include a pair of *nostrils* (or *external nares*) situated a little ahead of the eyes. The nostrils lead to *nasal passages* which open into the roof of the buccal cavity. The glottis opens into the *larynx* which is box-shaped and is made up of a pair of *arytenoids* and a single *cricoid* (forming the base) cartilages. The larynx opens into the *trachea* which is narrow, tubular and beset with complete cartilaginous *tracheal rings*. The trachea is bifurcated into two and forms a pair of narrow passages called the *branchi*. Each bronchus enters into a *lung*. The lungs are elongated sac-like structures. The right lung is slightly larger than the left one. Internally each lung is incompletely divided into small chambers by developing many incomplete septa (Fig. 7.7). These chambers are called the

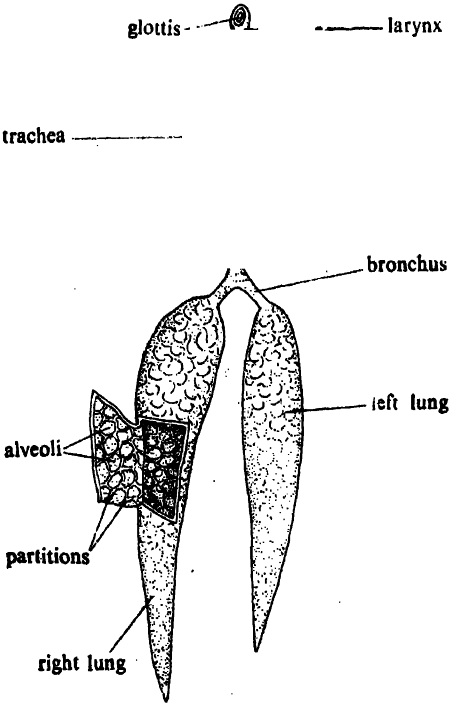


Fig. 7.7. Respiratory system of *Calotes*. A portion of the right lung is cut open to show the alveoli.

alveoli. In the distal part of the lung, such chambers are absent. This nonpartitioned posterior part of the lung is considered as *reservoir* for the residual air. It constitutes about one third part of the whole lung. The wall of the lung is made up of squamous epithelium.

Mechanism of respiration. The chemical mechanism of respiration is basically similar in all vertebrates, but the physical mechanism varies in many forms. The physical mechanism is divided into two steps. The steps are: inspiration and expiration. *Inspiration* is caused by the movement of the intercostal muscles which raise the ribs and by increasing the volume of thorax reduce lung pressure and cause an inflow of air. *Expiration* is caused by lowering the ribs through the contraction of intercostal muscles and decreasing thoracic volume. By expiration carbon dioxide and moisture are removed.

CIRCULATORY SYSTEM

Transportation of various essential substances within an organism is conducted by the circulatory system. The circulatory system consists of (A) the *heart* which is an efficient machine to propel the (B) fluid vehicle, the *blood* into the pipelines of (C) *arteries* and (D) *veins.*

Structure of Heart. The heart is situated in the thoracic cavity and ventral to the alimentary canal. It is enveloped by thin and transparent *pericardium.* The pericardium is composed of two layers. The inner layer is fused with the heart, while the outer one is free. A small thread-like structure situated at the apex of the ventricle, forms a bridge between the two pericardial layers.

The heart consists of a *sinus venosus,* two *auricles* and a *ventricle.* The ventricle is partitioned internally by an incomplete vertical *interventricular septum.* The conus arteriosus and truncus arteriosus are absent in Calotes and the arches emerge out directly from the ventricular cavity. The sinus venosus is situated dorsally and opens into the right auricle through *sinuauricular aperture.* The sinus venosus is thin walled and ill developed. It is restricted to the dorsal side of the right auricle. The nonprominent nature of the sinus venosus may be regarded as a sign of its being fused with the right auricle as in birds and mammals. The two auricles open jointly into the ventricle through the *auriculoventricular aperture.* The interauricular septum is large and extends into the ventricular cavity through the auriculoventricular aperture and thus divides the aperture into two. The free tip of the septum is bifurcated. The inner walls of the auricles are provided with fibres of muscles called the *musculi pectinati.*

The thick walled ventricle (Fig. 7.8B) is provided internally with an *interventricular septum* which divides it incompletely into left and right halves. This partition has become complete in crocodiles except for an aperture called *foramen of Panizza.* The foramen of Panizza is a communicating aperture between the left and right systemic arches just at the point of crossing after

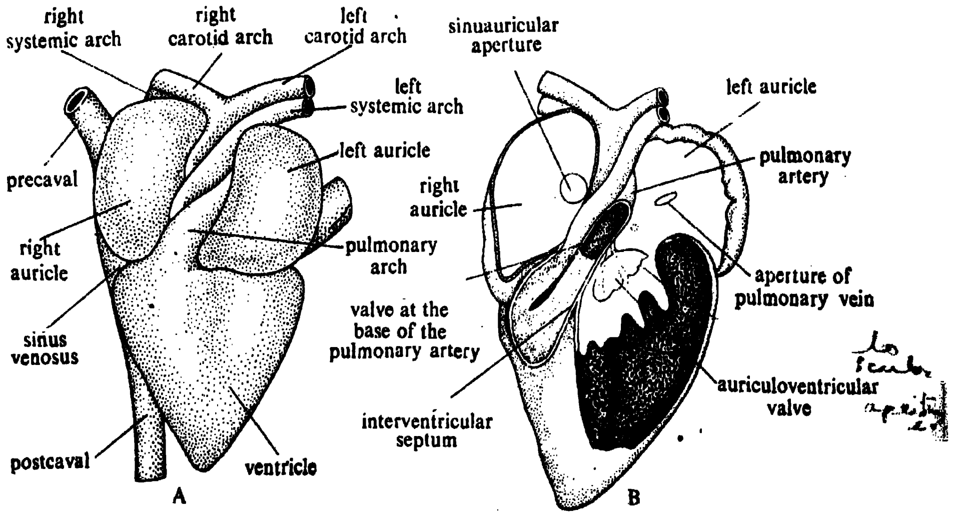

right systemic arch
right carotid arch
left carotid arch
left systemic arch
left auricle
precaval
right auricle
pulmonary arch
sinus venosus
postcaval
ventricle
A
sinuauricular aperture
left auricle
pulmonary artery
right auricle
aperture of pulmonary vein
valve at the base of the pulmonary artery
interventricular septum
auriculoventricular valve
B

Fig. 7.8. Heart of *Calotes.* A. Ventral view. B. Sectional view (longitudinal).

their emergence from the ventricle. The inner cavity of the ventricle has been arbitrarily divided into three regions namely, *cavum pulmonale* situated in the right side, *cavum venosum* (or the middle portion) and *cavum arteriosum* (or the left hand portion). In the middle of the ventricle and close to the line of demarcation between the auricles and ventricle, there are three apertures from which the aortic arches arise. The inner wall of the ventricle is provided with thick interlacing muscles called *columnae carnae*. There are bunches of thread-like muscle fibres called *chordae tendineae* by which the valves remain attached to the columnae carnae.

(The different compartments of the heart are intercommunicated by apertures having swing door-like flaps called the *valves*. These valves control the passage of blood and direct the flow in one direction. The valves present in the heart of Calotes are: (*a*) A pair of leaf-like valves in the sinu-auricular aperture. (*b*) Sphincter muscle acting as valve in the opening of pulmonary vein into the left auricle. (*c*) A pair of leaf-like valves formed by the bifurcation of the interauricular septum in the auriculo-ventricular aperture. (*d*) Three semilunar valves in the orifices from which the arterial arches arise.) About different valves

(The walls of the heart are provided with three histological layers common to all blood vessels, i.e., *tunica intima*, *tunica media* and *tunica adventitia* from inner to the outside. Of these three layers, the tunica media is peculiar in having specialised cardiac muscles showing striations and branchings. The heart is supplied with the cardiac branch of 10th cranial nerve.)

Mechanism of circulation through heart. In Calotes, the circulatory circuit is double. There is pulmonary or lesser circulation and systemic or greater circulation. Pulmonary circulation is conducted by the pulmonary arteries which carry deoxygenated blood to the lungs. In the lungs the blood becomes oxygenated and returns to the left auricle by the pulmonary vein. The left auricle pours its content into the ventricle through the auriculoventricular aperture. In the greater circulation deoxygenated blood returns to the sinus venosus by precaval and postcaval veins. The sinus venosus opens into the right auricle. The right auricle empties its content into the ventricle.

The ventricle sends blood for circulation into the different parts of the body through the systemic and pulmonary arches. The entry and exit of blood in the ventricle is so beautifully arranged that a major quantity of oxygenated blood is always forwarded to the brain region. As the ventricle is incompletely divided, the admixture of oxygenated and deoxygenated blood occurs thrice in Calotes once in the cavum venosum, once in the dorsal aorta and another in the left ductus caroticus. Thus though the ventricle in Calotes is morphologically incompletely divided, there is a tendency for the physiological separation of the two types of blood, at least in two auricles completely and in the ventricle partially. From this point, the heart of Calotes is biologically more advanced than that of Bufo.

Blood

Blood of Calotes is red in colour and is made up of plasma and blood cells. The red blood corpuscles are biconvex, elliptical in outline and each bears an elliptical nucleus. The white blood corpuscles are irregular in outline, nonpigmented and each bears a spherical nucleus.

Arterial System

Of the six pairs of arterial arches joining the dorsal aorta to the ventral aorta during embryonic development of arteries, the third, fourth and sixth pairs persist in adult Calotes and other reptiles. As the ventricle in Calotes and other reptiles tends to divide into left and right ventricles by the development of interventricular septum, the base of the ventral aorta splits into three parts, two of which remain in the right part of the ventricle and the third goes to the left part of the ventricle. Thus from the ventricle of Calotes arises three aortic arches. These arches are: (1) one pulmonary aorta and (2) two systemic aortae, right and left (Fig. 7.9). These three aortae are wound around themselves at the source and undergo about one and half turns round each other. The aortae are covered at the base by a fibrous sheath and thus appear tubular.

Pulmonary aorta. It arises independently from the right portion of the ventricle and soon splits into two branches, each entering into a lung. It carries deoxygenated blood.

Left systemic aorta. This aorta originates independently from the right (left to pulmonary aorta) portion of the ventricle and moves forward for some distance. Then it curves round the heart and goes downwards to meet the right systemic aorta a little posterior to the ventricle. It carries mostly the deoxygenated blood. One or two small arteries are found to have originated from the posterior part of the left systemic arch to supply the oesophagus. The arteries are called the oesophageal arteries.

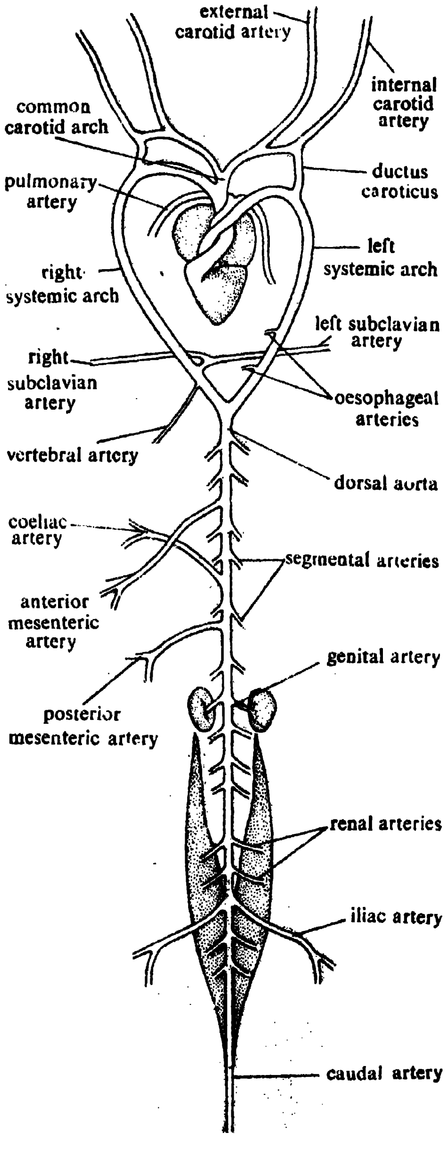

external carotid artery
common carotid arch
internal carotid artery
pulmonary artery
ductus caroticus
left systemic arch
right systemic arch
left subclavian artery
right subclavian artery
oesophageal arteries
vertebral artery
dorsal aorta
coeliac artery
segmental arteries
anterior mesenteric artery
genital artery
posterior mesenteric artery
renal arteries
iliac artery
caudal artery

Fig. 7.9. Arterial system of *Calotes*.

Right systemic aorta. This important aorta emerges independently from the left portion of the ventricle and moves forward and then curves to the right side of the heart. It meets the left systemetic aorta posteriorly to form the dorsal aorta. It carries oxygenated blood. From the apex of the curvature of the right systemic aorta arises a single and common *carotid artery* which advances anteriorly and then splits into four arteries. The inner pair of these four branches form the *external carotid arteries* while the outer pair forms the *internal carotid arteries*. The external carotids and their branches supply blood to face and mouth, while the internal carotids and their branches supply blood to the brain. Thus it is to be noted that carotid arteries do not arise independently from the ventricle as they do in amphibians but instead arise from the right systemic aorta. And as the right systemic arch carries oxygenated blood to anterior organs, specially the brain, this arch is supplied with oxygenated blood. The two internal carotids are connected to the systemic aorta of the corresponding sides by *ductus caroticus*. The ductus caroticus represents the remnant of embryonic radices between the third and fourth aortic arches. The right systemic aorta before its meeting with the left systemic aorta gives rise to a *subclavian artery* which bifurcates into two and supplies the forelimbs. From the right systemic aorta a *vertebral artery* also originates to send blood to the vertebral column.

The right and left systemic aortae unite a little behind the heart and give rise to the *dorsal aorta* which runs posteriorly and gives branches to visceral organs and posterior parts of the body. The following arteries originate from the dorsal aorta chronologically along the anteroposterior axis. These are: (1) *Anterior mesenteric artery.* Single and supplies blood to the small intestine. (2) *Coeliac artery.* Supplies blood to stomach, liver, spleen, pancreas. (3) *Posterior mesenteric artery.* It supplies blood to large intestine. (4) *Intercostal arteries.* Several pairs which supply blood to body wall, neural canal and body muscles. (5) *Genital arteries.* 1 pair, supplies blood to the gonads. (6) *Renal arteries.* 2 to 4 pairs, supply blood to the kidneys. (7) *Lumbar arteries.* Several pairs, supply blood to the neural canal, body muscles and skin of the lumber region. (8) *Iliac arteries.* 1 pair, supplies the hindlimbs. (9) *Caudal artery.*

Posteriorly the dorsal aorta continues as caudal artery and supplies the tail.

Venous system

The deoxygenated blood from the different parts of the body is brought back to heart by means of veins except the pulmonary veins which carry oxygenated blood. The veins run parallel to the arteries, appear dark and in position are superficial to arteries.

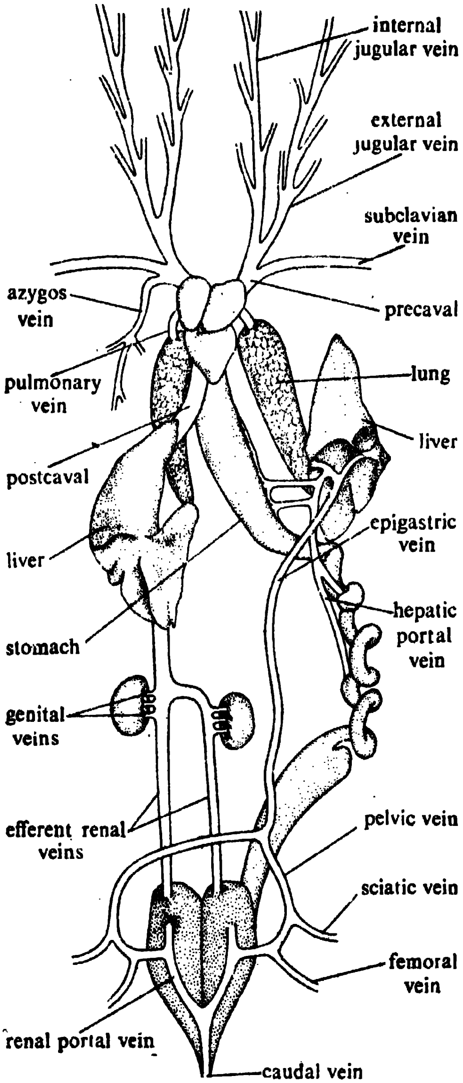


Fig. 7.10. Venous system of *Calotes*. The posterior part is semidiagrammatic.

The central meeting arena of all veins in the body is the sinus venosus. Sinus venosus is a triangular structure and its two base angles receive left and right *precavals* while the apex receives a single median *postcaval* (Fig. 7.10). Each precaval vein has been formed by the union of three veins. These are: (1) the *external jugular* which brings back blood from the floor of mouth and tongue, (2) the *internal jugular* which drains blood from the brain and (3) the *subclavian* which draws blood from the forelimb. The right precaval gets an *azygos vein.* The postcaval is constituted by the large median vein which is formed by the union of right and left *efferent renal veins* emerging from the two kidneys. *Genital veins* join the left and right efferent renal veins before their union. A pair of stout but short *hepatic veins* joins the median postcaval before its entry into the sinus venosus.

A median *caudal vein* carries blood from the tail region. The caudal vein ultimately bifurcates into two veins and enter into the kidneys. Each vein gives rise to the *renal portal vein* to the kidney and *pelvic vein* which receives *femoral* and *sciatic veins* from the hindlimb. The pelvic veins unite to form a median *epigastric* (or *anterior abdominal vein*) which ultimately opens into the left liver. The anterior abdominal vein and the postcaval is free of each other except through the renal portals in the kidneys. The blood from the visceral organs, i.e., stomach, intestine, pancreas, etc., enters into the left lobe of liver by a *hepatic portal vein.*

In Calotes both renal portal and hepatic portal systems are present. These systems have got many advantages and fulfil the demand for a second set of capillaries through which blood must flow. The organisms having such a portal system are always provided with double supplies of blood, arterial and venous.

The pulmonary venous circuit comprises of two *pulmonary veins*, one originating from each lung. These two pulmonary veins unite and form one common pulmonary vein which opens into the left auricle. The pulmonary veins bring oxygenated blood to the heart from the lungs.

NERVOUS SYSTEM

The nervous system of Calotes consists of (A) *Central nervous system*, (B) *Peripheral nervous system* consisting of cranial and spinal nerves which originate from brain and spinal cord respectively and (C) *Autonomic nervous system* (or *sympathetic nervous system*).

Central nervous system

The brain and the spinal cord constitute the Central Nervous System.

Brain. The brain is encased in the cranium. The nervous tissues of the brain are protected by two meninges called the *piamater* and *duramater*. The piamater remains in close contact with brain and it is highly vascular. The duramater is just outside the piamater and is mainly fibrous in nature. The two coverings remain separated from each other and the space between them is called *subdural space*.

Brain of an adult Calotes is differentiated into (*a*) Forebrain, (*b*) Midbrain and (*c*) Hindbrain (Fig. 7.11A). The forebrain consists of *telencephalon* anteriorly and *diencephalon* posteriorly. From the sidewall of telencephalon emerges a pair of sac-like projections called the *olfactory lobes*. The posterior part of the telencephalon is elongated and is called *cerebral hemisphere* or *cerebrum*. The diencephalon bears on the dorsal surface two projections called *parietal organ* and *pineal body*. The parietal organ is situated anterior to the pineal body (Fig. 7.11D,E). Another projection called the *paraphysis* is present in a reduced condition. From the ventral side of the diencephalon hangs a funnel-like structure called the *infundibulum* on the apex of which is situated the *pituitary body* or *hypophysis* (Fig. 7.11C).

The midbrain consists of a pair of oval *optic lobes* or *corpora bigemina* which arise as projections of the dorsolateral walls. Ventral to the optic lobes, there is a pair of longitudinal bands or peduncles called

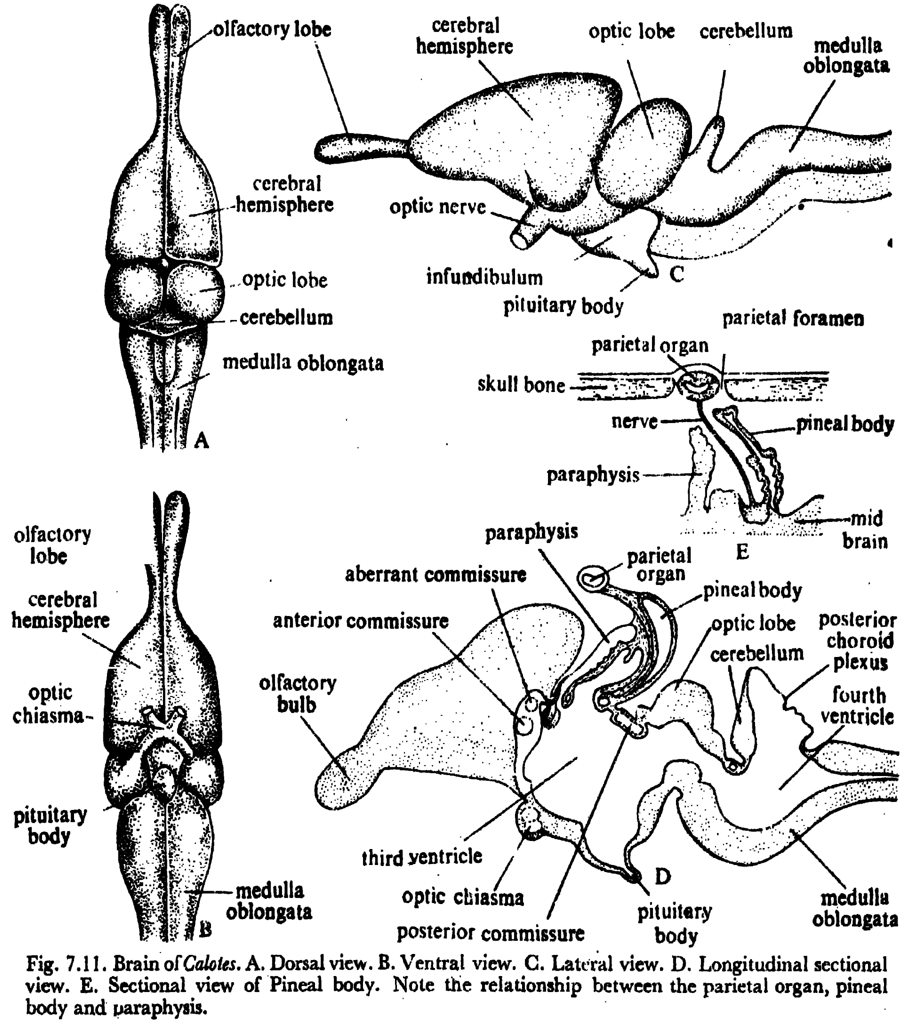

olfactory lobe
cerebral hemisphere
optic lobe
cerebellum
medulla oblongata
A
olfactory lobe
cerebral hemisphere
optic chiasma
pituitary body
medulla oblongata
B
cerebral hemisphere
optic lobe
cerebellum
medulla oblongata
optic nerve
infundibulum
pituitary body
C
parietal foramen
parietal organ
skull bone
nerve
pineal body
paraphysis
mid brain
E
paraphysis
parietal organ
aberrant commissure
pineal body
anterior commissure
optic lobe
posterior choroid plexus
cerebellum
olfactory bulb
fourth ventricle
third ventricle
D
optic chiasma
pituitary body
medulla oblongata
posterior commissure

Fig. 7.11. Brain of *Calotes*. A. Dorsal view. B. Ventral view. C. Lateral view. D. Longitudinal sectional view. E. Sectional view of Pineal body. Note the relationship between the parietal organ, pineal body and paraphysis.

crura cerebri which connect the hindbrain to the midbrain. The hindbrain consists of narrow and less convoluted *metencephalon* or *cerebellum* and a long *myelencephalon* or *medulla oblongata* which continues posteriorly as the spinal cord.

Thickenings inside the different brain regions. The roof of the cerebral hemispheres is thin but the ventrolateral walls are thick. The thick region is called *corpus striatum.* The roof of the cerebral hemispheres is called the *neopallium,* because the gray matters are situated on the outer margin. The roof of diencephalon is thin, highly vascular and is called the roof-plates (Fig. 7.11D). The lateral walls are called *thalami* and the floor is called *hypothalamus.* Parietal and pineal bodies arise from the roof-plate. The thalamus is thick. From the hypothalamus arises the infundibulum. The roof of the mesencephalon becomes thick to give rise to the optic lobes. It's floor is also thick and gives rise to the crura cerebri. The roof of the metencephalon is thin and nonnervous but the floor is thick. The myelencephalon is similar to metencephalon in regard to its floor and roof.

Ventricles. Internally the brain bears cavities which are continuous to one another and to the spinal cord. The cavity is filled with *cerebrospinal fluid.* The cavities in the cerebral hemispheres are called *lateral ventricles* or *first and second ventricles.* The diencephalon contains the *third ventricle* while the *fourth ventricle* is situated in the medulla oblongata. The two lateral ventricles are communicated to the third ventricle or *diacoel* by a small opening called *foramen of Monro.* The third and fourth ventricles or mesocoels are communicated with each other by a narrow passage called *iter* or *aqueduct of Sylvius.*

Commissures in Brain. Two sides of the brain are connected at places by transverse bands of nerves called the commissures.

The commissures are: (1) *Anterior commissure.* A wide transverse tract of nerve fibres connecting the two corpora striata. (2) *Habenular commissure.* Anterior to epiphysis and situated between epithalamic ganglia. (3) *Aberrant commissure.* Runs through the lamina-terminalis and joins olfactory lobes. The presence of abberant commissure in the brain of Calotes is regarded as the most important diagnostic feature. (4) *Hippocampal commissure.* Hippocampus is the swollen part of the mid-posterior region of the cerebrum. The two hippocampi are connected by the hippocampal commissure. (5) *Posterior commissure.* It connects the posterior part of the two optic thalami and is situated just in the junction of diencephalon and mesencephalon.

Spinal cord. It is the posterior prolongation of the brain through the neural canal. Its walls are thick and the roof and the floor bear dorsal and ventral furrows. Externally the spinal cord is made up of white matter consisting of medullated nerve fibres and internally there is grey matter containing ganglionic cells and non-medullated fibres.

Peripheral nervous system

The peripheral nervous system consists of nerve fibres which are either sensory or motor or mixed. The cranial and spinal nerves constitute this system.

Cranial nerves. There are 12 pairs of cranial nerves in Calotes. The origin, distribution and biological nature of the first to tenth pairs of cranial nerves are exactly similar to that of *Bufo* already discussed in Chapter 6 (*vide* page 212). Figs. 7.12 will give an idea of the origin and the ramifications of the fifth, seventh, ninth and tenth cranial nerves in Calotes. The eleventh and twelfth pairs of cranial nerves are the (A) Spinal accessory and (B) Hypoglossal respectively.

The spinal accessory (XI) originates from the posterior part of medulla oblongata as efferent fibres and join with the vagus. Along its course, this nerve receives series of rootlets from the spinal cord. The spinal accessory nerve supplies mostly to the striated muscles of the pharynx, larynx and also to the autonomous nervous system. It is a sensory nerve. The hypoglossal nerve (XII) is also a sensory nerve which originates from the medulla oblongata and innervates the muscles of the tongue and controls its movements during feeding.

Spinal nerves. There are several pairs of spinal nerves originating from the spinal cord and emerge out from it between the vertebrae. The spinal nerves are mixed type of nerves. They originate separately and independently but ultimately combine to form a single cord. They originate by a *dorsal root* which is sensory and a *ventral root* which is motor in nature. Each spinal nerve divides into four branches or *rami.* These branches are: (1) *dorsal branch,* thin, short and supplies sense organs, gland and muscles, (2) *ventral branch*, long, thick and supplies hypoaxial organs, (3) *meningeal branch*, small and goes back to supply the neural canal and (4) *ramus communicans*—which communicates with autonomic nervous system. Several spinal branches often meet together and form *plexus*.

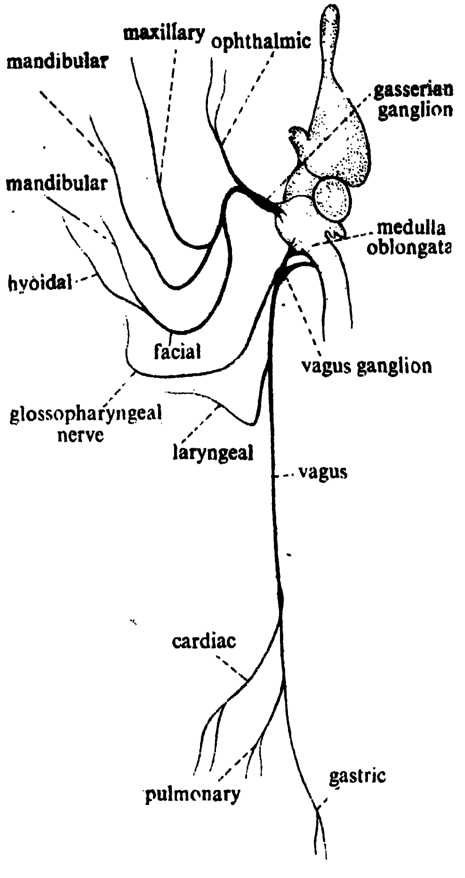


Fig. 7.12. Showing the origin and distribution of Vth, VIIth, IXth and Xth cranial nerves of *Calotes*.

Autonomic nervous system

This system consists of a chain of complicated *ganglia* with receptor and effector nerves formed mostly by the offshoots from the ventral branches of the spinal nerves. The branches from these ganglia innervate muscles of heart, lung, digestive system and glands which work continuously and are not controlled by will. Autonomic nervous system comprises of two divisions of nerves which are structurally similar but functionally antagonistic. These are: (*a*) sympathetic nerves having activating action and (*b*) parasympathetic nerves which have inhibitory action.

SENSE ORGANS

The sense organs are highly developed in *Calotes*.

Olfactory organs

The olfactory organs for smell in Calotes are the '*nasal chambers*'. The nasal chamber or passage extends between the external and internal nares. The anterior part of the nasal chamber is devoid of any sensory cells while the posterior part bears many spindle-shaped cells connected to the twig of the olfactory nerve. Highly pigmented sensory epithelial cells cover the spindle-shaped cells. To enlarge the surface of exposure, the epithelium of nasal wall is extended into a single shelf like *concha*. Calotes has single unrolled concha one on either side.

Organ of Jacobson

An accessory structure, called *organ of Jacobson* is associated with the olfactory organ of Calotes (Fig. 7.13B). It is a cavity derived embryonically from the olfactory cavity, lined with sensory epithelium and innervated by both olfactory and trigeminal nerves. In position, it is ventromedian to the nasal cavity. It acts as a chemoreceptor and it is highly developed in lizards and snakes.

Organ of sight

The sense organ for sight consists of a pair of eyes which are lateral in position. The eyes are provided with eyelids and glands. The upper eyelid is small and less movable and the lower eyelid is large and more movable. The third eyelid or nictitating membrane is transparent. Harderian glands supply the third eyelid, while lacrimal glands make their first appearance in reptiles.

The wall of the globular eye is made up of several layers (Fig. 7.13A). The innermost layer bounding the posterior part of the eye is made up of *retina*. It is supplied with fine branches of nerves from the optic nerve. A vascular projection (*ectodermal conus*) arises from the blind spot region of retina. The layer outside the retina is called the *choroid* which is made up of an inner pigmented layer and an outer vascular layer. Outside the choroid is situated

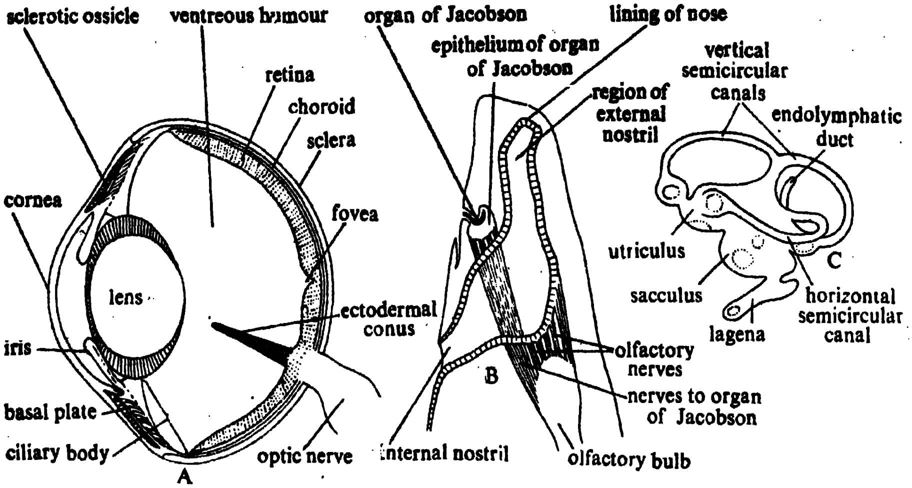

sclerotic ossicle
ventreous humour
retina
choroid
sclera
cornea
fovea
lens
ectodermal conus
iris
basal plate
ciliary body
optic nerve
A
organ of Jacobson
epithelium of organ of Jacobson
lining of nose
region of external nostril
olfactory nerves
nerves to organ of Jacobson
internal nostril
olfactory bulb
B
vertical semicircular canals
endolymphatic duct
utriculus
sacculus
lagena
horizontal semicircular canal
C

Fig. 7.13. Sense organs of *Calotes*. A. Section of eye. B. Showing the relationship of the organ of Jacobson with the nasal cavity. C. Internal ear. Circles shown in dotted line indicate the sensory areas.

the *sclerotic* layer which is protective in nature. The front of the eye is occupied by lens which is a clear ball derived from the skin (ectoderm). The iris is a pigmented and muscular ring in front of the lens. The iris is a prolongation of the choroid. The aperture in the iris in front of the lens is called the *pupil*. The front part of the eye is protected by *cornea* which is continuous with the sclera. The cornea is protected by *conjunctiva*, which is epidermal in nature. The lymph space between cornea and iris remains occupied by *aqueous humour* and the inner space between lens and retina remain filled with jelly-like *vitreous humour*.

Auditory sense organ

This sense organ comprises of ears which perform two fold functions—hearing and maintenance of equilibrium. The ear of Calotes is made up of two parts, (1) the middle ear and (2) the internal ear. External ear is absent.

Middle ear. It is a tubular cavity with its outer opening being covered by the *tympanic membrane* situated behind the eye. The membrane is slightly depressed and is perforated by very minute apertures. The inner end of the tube is covered by a very thin membrane. A bony rod-like structure called *columella auris* is situated inside the tube of the middle ear. The role of this structure is to transmit the sound waves. The middle ear is communicated to the buccal cavity by a narrow but long tube called the *eustachian tube*. The middle ear communicates with the internal ear through a circular structure called *fenestra ovalis*. The internal ear is situated in a bony capsule. The space between the capsule and internal ear is filled in with perilymph. The internal ear is demarked into an upper *utriculus* which is tubular and slightly bent and a lower *sacculus* which is sac-like. Lagena or rudimentary cochlea is attached to the ventromedian side of the sacculus (Fig. 7.13C). From the utriculus arises a tubular structure called the *ductus endolymphaticus* which opens beneath the duramater of brain.

There are three semicircular canals attached to the utriculus by both ends. Each semicircular canal is swollen at one end. The swollen part is called ampulla. The ampullae of anterior semicircular canal and horizontal semicircular canal are situated side by side while those of posterior semicircular canal and horizontal canal are situated at a distance. Minute masses of Caco$_3$ present inside the ampullae help in maintaining balance. These pieces of Caco$_3$ are called *statoliths* or *autoliths*. The sacculus, utriculus and the three semicircular canals remain filled with a liquid called the *endolymph*.

EXCRETORY SYSTEM

The excretory system of Calotes consists of a pair of *metanephric kidneys* situated in the abdominal cavity. These are retroperitonial in position and lie one on either side of the vertebral column. Each kidney is dark-red in colour and is lobed. The kidneys are free at the anterior end but are united along the inner margins at the posterior part. The posterior ends of the kidneys run over the cloacal chamber.

Histologically each kidney is made up of a central portion, the *medulla* and a peripheral portion, the *cortex*. The cortex contains numerous *renal* or *Malpighian corpuscles*. Each corpuscle consists of a *Bowman's capsule* which is a double walled cup of epithelial cells. The space between the two layers of the capsule is the beginning of the renal tubule. In the concavity of the Bowman's capsule lies the glomerulus which is a spherical tuft of arterial capillaries. The renal tubules open into the collecting tubule which communicates with the ureter. The kidney has a double set of capillary system. One set is formed by the afferent and efferent renal arteries while the other set is formed by renal and renal portal veins.

There is a pair of *ureters* arising one from each kidney. The ureters are short and open into the cloaca separately. From the lateral wall of the cloaca arises a single *urinary bladder* which is allantoic in origin. The urine of Calotes is semisolid in consistency and contains uric acid.

Ecdysis

Ecdysis is nothing but periodical peeling off of skin. Ecdysis occurs in Calotes and thus scales lodged in skin are shed. It is assumed that some amount of nitrogenous elements are thrown out during the process of ecdysis. So ecdysis is also a process of excretion.

REPRODUCTIVE SYSTEM

Sexes in Calotes are separate and it is difficult to distinguish between the male and female from external morphological features.

Male reproductive system. This system includes a pair of *testes* situated in the abdominal cavity which remain suspended by a special dorsal fold of the mesentery called *mesorchium*. The testes are white oval bodies. The testis of the right side is larger in size compared to that of the left side and situated slightly higher up in the abdominal cavity. From the inner surface of each testis runs the *epididymis* which receives the *vasa efferentia*. The epididymis proceeds posteriorly as *vas deferens* (Fig. 7.14A). Two

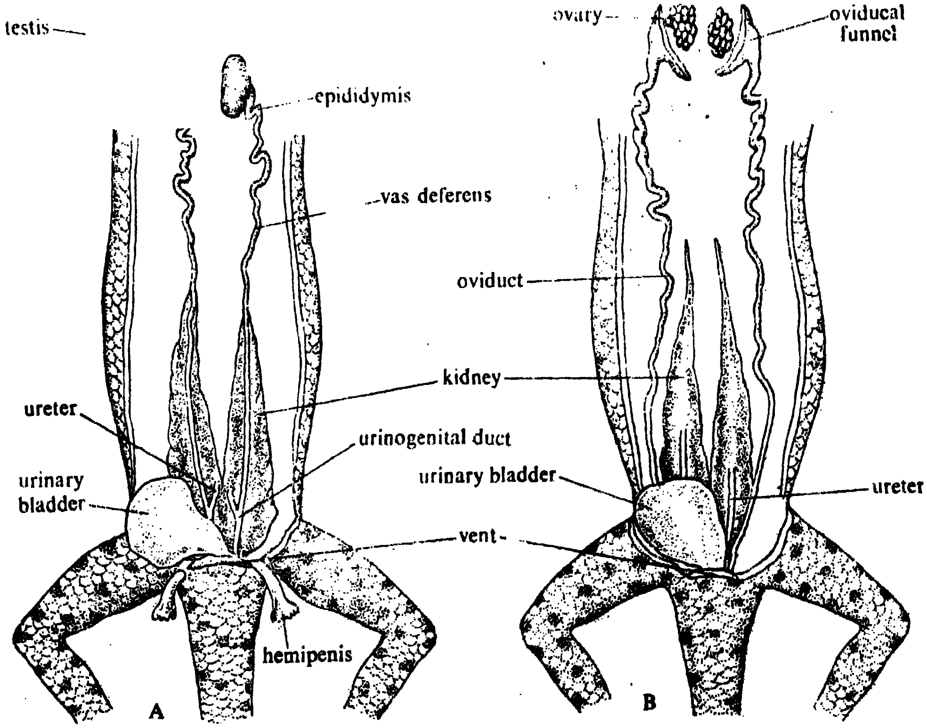


Fig. 7.14. Urinogenital system of *Calotes*. A. Male. B. Female.

vasa deferentia open separately by small papillae into the cloaca but before opening into the cloaca each receives the ureter of the, corresponding side. So through this common duct both urine and male gametes pass into the cloaca which is designated as the urinogenital duct. The posterolateral side of the cloaca is provided with a pair of *copulatory sacs* each of which houses a *hemipenis*. The hemipenis is eversible.

Female reproductive system. This system includes a pair of *ovaries* which have similar position as that of testes (Fig. 7.14B). Each ovary is fixed to the dorsal side by a special fold of mesentery called the *mesovarium*. The female gonoduct is called the *oviduct*. The oviduct is attached with the bodywall by a special fold of peritoneum called the *broad ligament*. The anterior end of the oviduct is wide, funnel-shaped, ciliated and is situated near the corresponding ovary below the level of lungs. The oviducts are not coiled but are folded which run posteriorly to open independently into the cloaca. The diameter of the oviduct shows gradual increase towards the posterior side in cross-section. The lower part of the oviduct is designated as the *uterus* where the eggs are stored temporarily prior to laying. In the anterior part of the oviduct there are many *albumen glands* and the posterior part is provided with *shell glands*.

Fertilization

In Calotes the fertilization is internal. Mature eggs are fertilized in the anterior part of the oviduct. The eggs are heavily yolked and are covered by calcareous shell.

Example of Reptilia—SNAKE

The different snakes under the suborder Ophidia are the objects of fascinating study. Snakes and lizards are so closely related that they are included under the order *Squamata*. The close relationship existing between them are easily understood when it is recalled that many lizards lack usuable limbs and some primitive snakes have vestigial legs (remnants of hindlimbs). Loss of limbs in snakes is essentially an aid of living in the subterranean realm. Snakes are considered as a flourishing group and are geologically more recent in their origin. Snakes have been evolved from the lizard-like reptiles in the Mesozoic era.

ANATOMICAL PECULIARITIES OF SNAKES

Due to the fossorial adaptation, snakes show many peculiar features (Figs. 7.15).

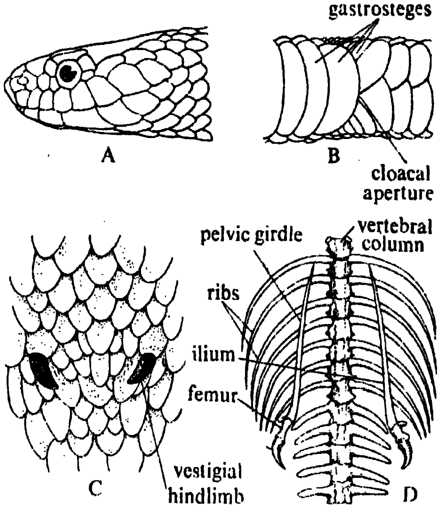


Fig. 7.15. A. Head of a snake showing the arrangement of head shields. B. Arrangement of scales on the ventral side of the body of a snake. C & D. Showing the vestigial hindlimbs in Python.

EXTERNAL FEATURES

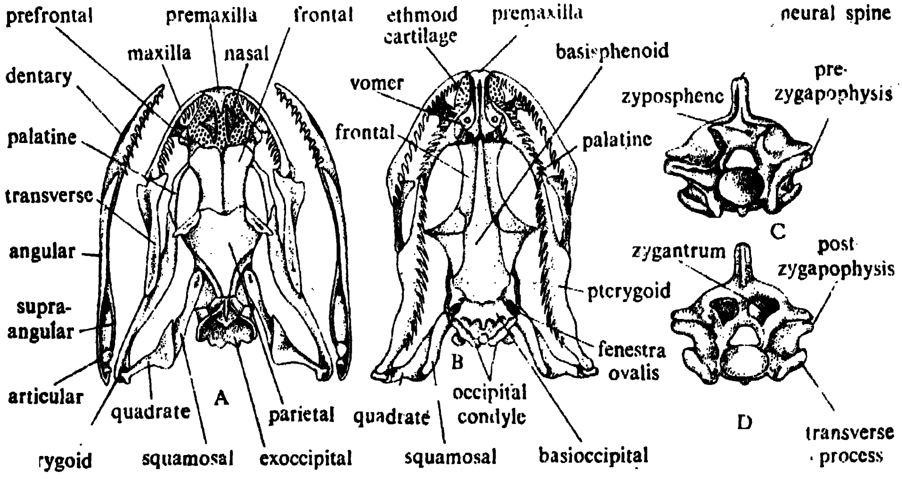
The body of snakes is extremely elongated and cylindrical. The limbs are usually absent, except in certain genera where traces of posterior limbs are present at the base of the tail and bear conical claws. Distinct neck is absent. The body is covered with *scales* and *shields*. The *osteoderms* are absent. The scales are usually small and overlap each other, but the shields are usually large and join each other by their margins. The head is covered mostly by the head shields (Fig. 7.15A). The head shields are named according to their placement. The shields situated in the mental groove on the ventral side between the rami of the lower jaws are called the *mental shields*. The mental shields are considered to be a peculiar feature. The other shields are: *frontal shield*, *superciliary shields*, *rostral shield*, *upper labial shields*, *nasal shield*, *preorbital shields*, *loreal shield*, *median labial shield*, *jugular shields*, *ventral shields*, etc. The scales on the ventral side of the body are broad and cover the body like transverse bands. These ventral scales are called the *gastrosteges* (Fig. 7.15B). The whole of the scaly epidermis is cast off several times in a year. This phenomenon is called the *ecdysis* or *moulting*. The head is more or less conical. The nostrils are terminally placed. The eyelids are fused over the eyes. The *tympanic membrane*, *tympanic cavity* and *eustachian tube* are absent. The *cloacal aperture* is a transverse slit. Males are provided with paired *copulatory organs*.

INTERNAL STRUCTURES

The internal structures of the snakes also become modified in response to their peculiar mode of living. An elongated and forked tongue is present. The base of the tongue is provided with a muscular sheath into which the tongue may be retracted. The teeth are conical, backwardly slanting and are fixed on jaw bones. The labial glands become modified into poison glands and do not help in digestion. The alimentary canal is relatively small. The stomach is elongated. The liver is elongated with unequal lobes. The lungs are asymmetrical, left lung is often small and sometimes absent. About half to one-third posterior part of lung serves as the reservoir of air. The elongated trachea opens at the anterior portion of buccal cavity and may be protruded between the two halves of the lower jaw. This is a modification for respiration during swallowing of prey. The heart is typically reptilian. The arterial arches are asymmetrically disposed and the *ductus caroticus* is absent. The kidneys are asymmetrical and elongated. The urinary bladder is absent. The gonads are asymmetrical. The males are provided with a pair of eversible copulatory organs, the apex of which may bear spiny projections. They are mostly oviparous in habit but some are viviparous. The eggs are moderately telolecithal and the egg shell is leathery. The brain is narrow, elongated and projected between the eyes. The parietal organ is absent. The organ of Jacobson is well developed.

The skull is streptostylic (i.e., the quadrate is highly movable) in nature and occipital condyle is distinctly tripartite. The fossae and interparietal foramen are absent. The parietals fused together to form a single piece (Fig. 7.16A). The frontals are provided with lateral projections which unite at the floor of the skull. The posterior border of orbit is formed by postfrontal. The premaxillae have united to form a single piece. The maxilla, palatine and pterygoid are movable. The quadrate and squamosal are loosely articulated with the skull. The squamosal is horizontal in position and extends beyond the posterior limit of skull (Fig. 7.16B). The palatine and pterygoid of one side do not unite with the fellows of opposite side. Basisphenoid is prolonged into rostrum. The epipterygoid is attached to pterygoid and maxilla. Interorbital septum is absent. The mandible is composed of several pieces of bones and the rami are united by ligaments. The teeth are present on maxilla, palatine, pterygoid and dentary.

The vertebrae are strongly procoelous and divisible into precaudal and caudal


prefrontal
premaxilla
frontal
maxilla
nasal
dentary
palatine
transverse
angular
supra-angular
articular
quadrate
A
parietal
rygoid
squamosal
exoccipital
ethmoid cartilage
premaxilla
vomer
frontal
basisphenoid
palatine
pterygoid
fenestra ovalis
B
occipital condyle
quadrate
squamosal
basioccipital
neural spine
zyposphene
pre-zygapophysis
C
zygantrum
post zygapophysis
D
transverse process

g. 7.16. A. Dorsal view of the skull and lower jaw of a nonpoisonous snake. B. Ventral view of c skull of a nonpoisonous snake. C. Anterior view and D. Posterior view of a precaudal vertebra of snake.

regions. Besides pre- and post-zygapophysis, extra articulating surfaces called *zygosphene* at the anterior face and *zygantra* at the posterior face are present (Fig. 7.16C.D). Some of the vertebrae may have a median hypophysis. Transverse processes are rod-shaped and well-developed. These processes at the caudal region are bifid. The ribs are hollow, single headed and present in all vertebrae except atlas. Distally the ribs are attached to ventral scales by ligaments to help in locomotion. The girdle bones and limbs are completely absent. Pelvic girdle is represented as a vestige in python.

POISON APPARATUS AND BITING MECHANISM OF POISONOUS SNAKES

The poison apparatus consists of a pair of *poison glands* and a pair of *fangs* (Fig. 7.17A). The glands are situated one on either side of the upper jaw. The poison glands are possibly the modified superior labial glands. Each gland is sac-like and provided with a narrow duct at its anterior end. The duct passes forward along the side of the upper jaw and loops over itself just in front of the fang and opens either at the base of the fang or at the base of the tunnel on the fang. The poison gland is held in position by ligaments. An *anterior ligament* attaches the anterior end of the gland to the maxilla. A *posterior ligament* runs between the gland and quadrate. Fan-shaped ligaments are situated between the side walls and squamoso-quadrate junction. The fangs are sharply pointed and are enlarged maxillary teeth which regenerate when lost. There are two types of fangs—open type and closed type (Fig. 7.17B-D). In open type as in cobras, the poison groove is open and in closed type as in vipars, the poison groove forms a tunnel having two openings, one at the base (intake aperture) and one near the apex (discharge aperture).

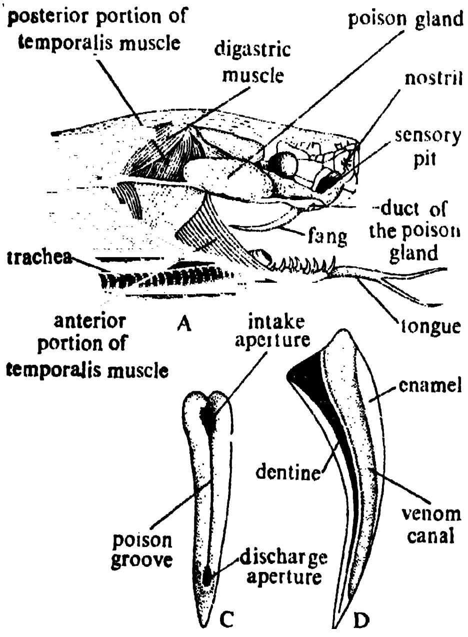


Fig. 7.17. A. Poison apparatus of snake. B-D. Different types of fangs. B & D in sectional view.

The poison apparatus is associated with specialised bands of muscles. These muscles are: (*a*) *Digastric*—attached to the squamosal of the skull at one end and the articular of the lower jaw. It helps in opening the jaws. (*b*) *Sphenopterygoid* or *Protractor-pterygoid muscle*—Attached anteriorly to the sphenoid region and posteriorly to the dorsal surface of the pterygoid. It assists in pulling the pterygoid forward. (*c*) *Anterior* and *posterior temporalis muscles*—attached to the side walls of the cranium and the lower jaw. They help in closing the lower jaw.

Biting mechanism

The mechanism of biting is a complicated process and the sequences of biting may be discussed in three observable steps. These are: (*a*) *Opening the mouth.* The digastric muscle contracts, as a result the mouth opens. (*b*) *Rotation of maxilla.* As the mouth opens the lower jaw moves forward and a rotation of the squamosal, quadrate and mandible in relation to each other occurs. Now the sphenopterygoid muscles contract. This contraction results in the forward movement of pterygoid and up-pushing of the ectopterygoid. The upward movement of the ectopterygoid brings about a rotation of the maxilla on its own axis round the lacrimal and as the end result the fang is raised and becomes directed forward (Fig. 7.18 A, B). The fang is nearly horizontal in position when the mouth remains closed. But during opening of the mouth to bite, the fang assumes almost vertical position. (*c*) *Closing of mouth.* This is brought about by the contraction of the temporalis muscles and sphenopterygoid muscles. The point of the fang is directed backward while the mouth is closed. It takes a longer time to open the mouth than to close it.

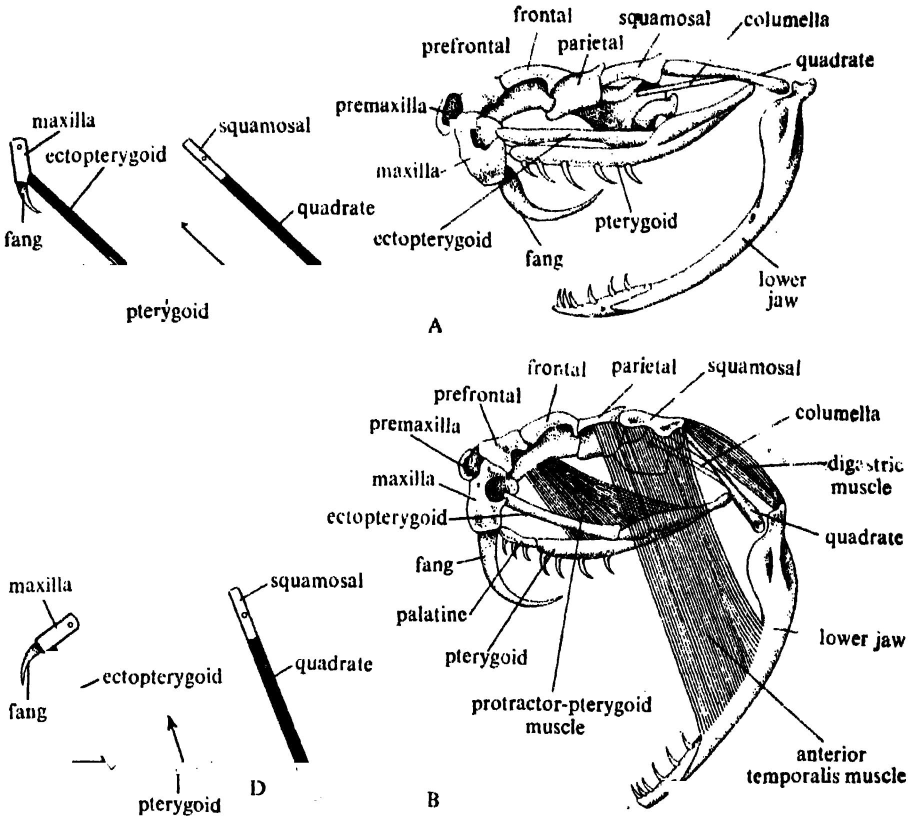

frontal
squamosal
columella
prefrontal
parietal
quadrate
premaxilla
maxilla
ectopterygoid
squamosal
maxilla
fang
quadrate
ectopterygoid
pterygoid
fang
lower jaw
pterygoid
A
frontal
parietal
squamosal
prefrontal
premaxilla
columella
digastric muscle
maxilla
ectopterygoid
quadrate
fang
maxilla
squamosal
palatine
lower jaw
quadrate
pterygoid
ectopterygoid
fang
protractor-pterygoid muscle
anterior temporalis muscle
pterygoid
D
B

Fig. 7.18. Showing partly opened (A) and fully opened (B) mouth of a poisonous snake. Note the relative position of the fang, maxilla, lower jaw, quadrate and squamosal. C and D, Schemes showing the relative position of principal bones involved in the erection of fang.

Transference of venom

During the contraction of the digastric muscle the posterior ligament is relaxed and during the rotation of the squamosal bone the fan-shaped ligaments are stretched to squeeze the walls of the gland. This makes the poison to come out of the gland through the duct and fang.

Nature of venom

Snake venom is a clear, transparent, pale yellow or straw coloured fluid and is in fact a pure solution of two or more protein materials. It is acidic in reaction and soluble in water and glycerine. The poison is precipitated in reagents like silver nitrate and permanganate of potash.

Effect of poison

The venom is generally introduced into the subcutaneous tissue and then it reaches the general circulation. When introduced directly into the vein the effect is instantaneous. The venom of different snakes acts differently.

(*a*) *Cobra poison.* The effects are observed within half an hour. Symptoms are geediness, high pulse rate, extreme salivation, partial paralysis of tongue and larynx, vomiting and contraction of pupil. The eyes remain sensitive to light and consciousness remain undisturbed. Respiration is shallow, ultimately ceases and death follows.

(*b*) *Viper poison.* The effects are observed within quarter of an hour. Symptoms are swelling of the wounded region, discolouration due to extra vasation, acute burning pain, pupil dilatation, high pulse rate, profuse vomiting and watery discharge from rectum. Eyes lose sensitivity to light and consciousness is affected. Extra vasation becomes extensive, swelling spreads and death comes. The poison of the two groups differ in properties though a viperrine can poison a colubrine and *vice versa.* The poison is effectless on members of same family.

TABLE CHORDATA–10

DIFFERENCE BETWEEN NONPOISONOUS AND POISONOUS SNAKES

	NONPOISONOUS SNAKES	POISONOUS SNAKES
1. Colour	Not bright.	Brightly coloured.
2. Shape of head	Elliptical.	Posterior portion is broad.
3. Hood	Absent.	Present.
4. Abdominal scale	Small.	Large, extend from side to side.
5. Head shield	Small.	Very large.
6. Loreal shield	Absent.	Present, shapes may be variable.
7. Mental shield	Small.	Fourth one is large.
8. Teeth	Uniform.	Maxillary teeth are large and are called 'Fangs'. Fangs are provided with groove or canal.
9. Poison gland	Absent.	Present.
10. Streptostylism	Less marked.	Well marked.

SOME INTERESTING REPTILES

Gecko. Lives in proximity to man and in trees, thatches, etc. About 30 cm in length having a tail shorter than head and body (Fig. 7.19A). The skin is granulated, spotted and coloured grey. The toes bear undivided adhesive lamellae (Fig. 7.19B). It can emit sound. They are useful as they devour insects, spiders, etc. House lizard, *Hemidactylus*, a member of Gecko family has divided adhesive lamellae.

Draco (or flying lizard). Small lizards with long tail having a parachute web on each side of the body supported by 4 or 5 pairs of long hinder ribs (Fig. 7.19E). These are carried in folded condition and spread out when the lizard takes a long leap. Generally they live in trees.

Varanus or Monitor. Tail is compressed and longer than the body (Fig. 7.19D). Size from head to tail is about 15 cm. Colour is black on variable grounds of yellow, olive and brown.

Uromastix. Spiny tailed lizard, with sandy colour.

Chameleon. Body is compressed; skin is granulated; tail is prehensile (See Fig. 7.20D); tongue is long, club-shaped and sticky which can be shooted out. Colour is changeable.

Phrynosoma. Popularly known as *horned toad* and has numerous small scales and a collar of sharp spines made of scales (Fig. 7.19G). It shows desert adaptation.

Iguano (or kamade dragons). It may attain length of 90 cm (Fig. 7.19C). The teeth are pleurodont and are very powerful. They are nearing extinction.

Heloderma. Measuring about 30 cm in length, brightly coloured with black and yellow spots, is the only poisonous lizard known (Fig. 7.20E). Figs. 7.20F and G show the position of the poison gland. This gland opens by numerous ducts. Each duct leads into the groove of a tooth.

Slow worms (or glass snakes). Belonging to the family Amphisbaenidae. These are degenerated lizards without limbs and scales (Fig. 7.19F). The eyes are small with eyelids and resemble snakes.

Typhlops (or worm snake). It is a small worm like burrowing snake. The eyes are hidden beneath the head scales and the teeth are absent in the lower jaw. The tail is stumpy and is either conical or end in a spine. They are harmless and found under stones or in burrows. It belongs to the family, *Typhlopidae*. Example: *Typhlops braminus*.

Glauconia or Him snakes (Fam. Glauconidae). It resembles the worm snakes but the upper jaw is toothless. The hipbones are much developed and hence the name. Example: *Glauconia blandfordi*.

Uropeltis or Sheid tailed snakes (Fam. Uropeltidae). It has a peculiar tail. The tail is short and ends abruptly in flat disc set at an angle to the axis of the body. Example: *Uropeltis grandis*.

Xenopeltis or Rainbow snake (Fam. Xenopeltidae). The body is covered by highly polished irridescent scales. Only a single species exists. Example: *Xenopeltis unicolour*.

Boas and Pythons (Fam. Boidae). They are readily recognised from all snakes by their giant size and construction. They are nonvenomous, have both the lungs and vestiges of pelvic girdle. Boas are viviparous while pythons are oviparous. Examples: *Python reticulatus*, *Boa constrictor*. *Anaconda* (*Eunectes*) of tropical South America is a water boa of great size.

Vipers (Fam. Viperidae) are well known for their most efficient venom injecting apparatus. The family is divided into two subfamilies—one having a facial pit (Crotalinae), the other without it (Viperinae). Examples: Pit-viper. Rattle snakes (*Crotalus*) are deadly poisonous and characteristic in having a 'rattle'. A rattle is a horny structure, gains a segment each time a snake sheds and helps in telling the age. Example: *Vipera russelli*.

Cobras and coral snakes (Fam. Colubridae) are all poisonous. Cobras have expansible hood and sea snakes have laterally compressed tail. Examples:

Naja naja, *Naja hannah*, *Dendrophis* (Mamta of Africa).

Crocodylus porosus. Indian crocodile, may measure 6 m. Very common in the eastern coast of India. They are fierce reptiles and dangerous man-eaters.

Crocodylus niloticus. They are the sacred crocodile of tropical Africa (Fig. 7.20A). They exhibit a peculiar friendly partnership with little birds belonging to the genus *Pluvianus* which enter into the kept-open mouth of the animals and remove parasites specially helminths from the root of teeth.

Alligator. This genus of crocodile is often confused with Indian crocodiles. Alligators (Fig. 7.20B) are not found in India and they are strictly restricted to China and South America.

Gavial gangeticus. Commonly known as 'Gharial' and occurs in the rivers of Burma and Indian rivers, specially the Ganges, Indus, Brahmaputra and Mahanadi (Fig. 7.20C). These are large crocodiles and may measure 6 m or above. Though they are fish eater and considered harmless to man, often ornaments have been encountered in their stomach. A display of ornaments obtained from the stomach of dead crocodiles may be seen in Calcutta Museum.

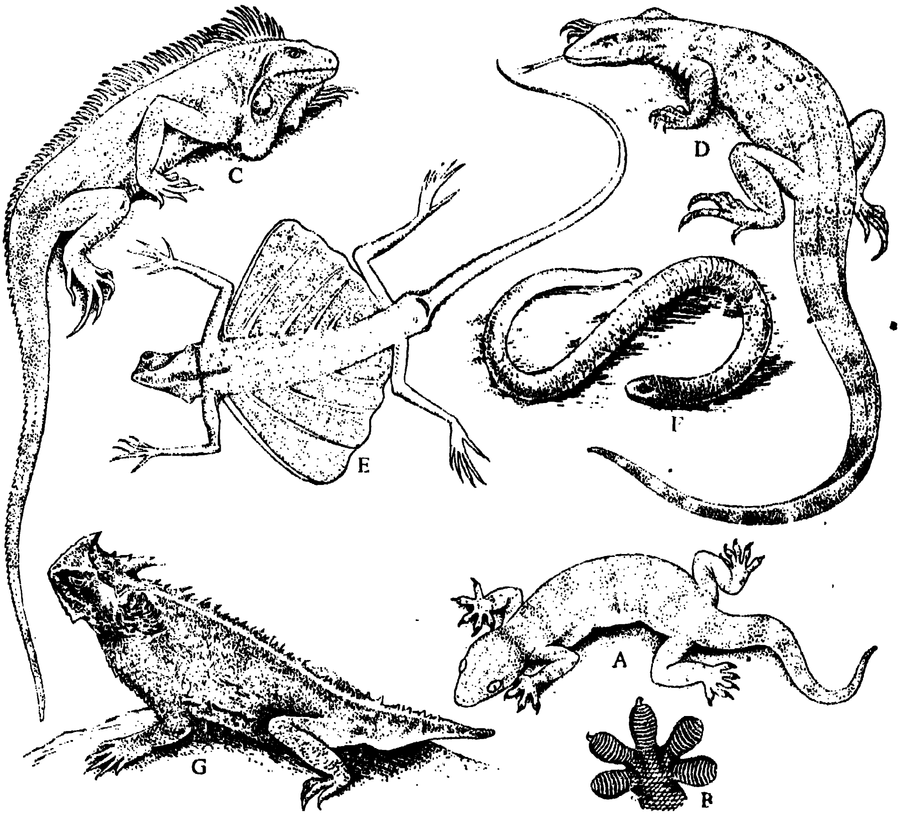


Fig. 7.19. Some interesting reptiles. A. *Gecko*. B Adhesive lamella of *Gecko*. C. *Iguana*. D. *Varanus* E. *Draco*. F Slow worm. G. *Phrynosoma*.

Chelone (*Ch. mydas*) is an edible turtle. It is green in colour. It attains a length of about 1 m and weighs between 150-175 kg. The carapace of chelone is depressed and the limbs are modified for swimming in water. The limb bones are flat and wide. The carpal and tarsal bones are fused and the digits remain embedded within the flipper. Claws are absent. Skull is of anapsid type. Female Chelone lays eggs at night on the beaches of remote islands. Eggs are laid in two or three batches and at intervals of about a fortnight. Chelone is on the verge of extinction because of excessive killing.

Trionyx is a most widespread turtle. Popularly it is known as soft-shelled turtle. The carapace lacks scales and is covered over by skin. The snout is elongated and ends in a small proboscis. The beak is horny and the lips are soft. Each limb bears three claws. The body length is less than a meter. They are strictly aquatic and feed on fishes, frogs and mollusks. The females lay about twenty spherical eggs at a time and bury the eggs in sand some distance from water. The Indian species, *Trionyx gangeticus* lives in Indian rivers.

CLASSIFICATION

Reptiles dominated the earth during the Mesozoic era. All the reptiles evolved from the Cotylosaurian stem forms which disappeared by the late Triassic times. Most of the reptiles failed to survive beyond Cretaceous period due to widespread elevation of earth surface coupled with chan-

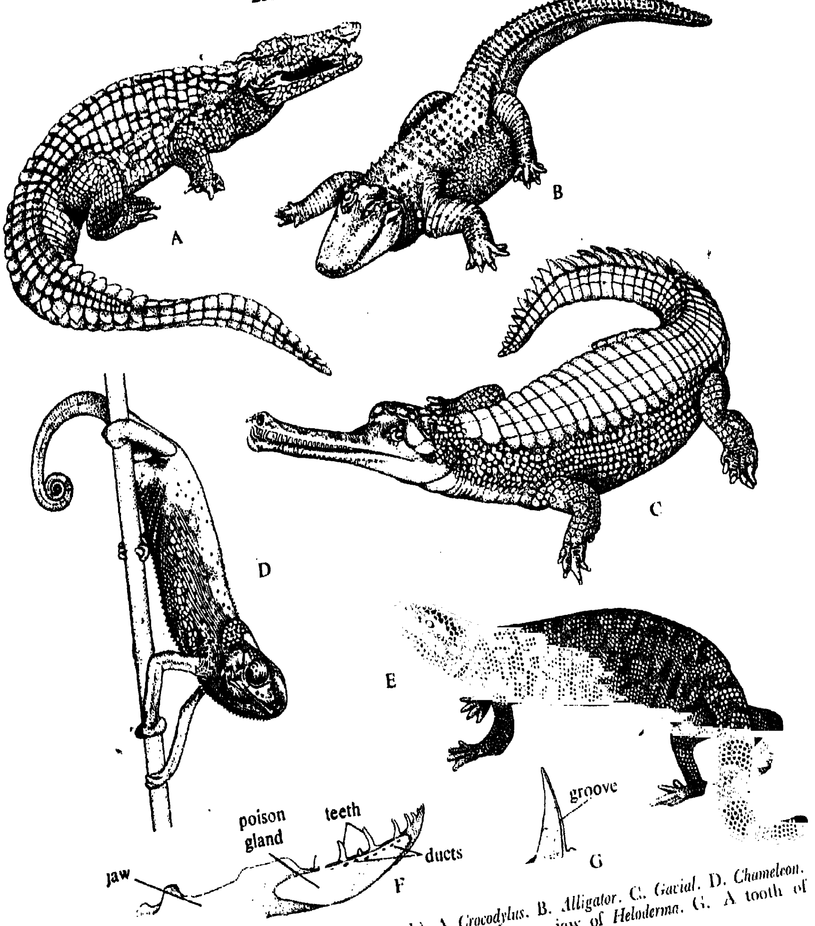


Fig. 7.20. Some interesting reptiles (Contd.). A. *Crocodylus*. B. *Alligator*. C. *Gavial*. D. *Chameleon*. E. *Heloderma*. F. Poison gland and its position in the lower jaw of *Heloderma*. G. A tooth of *Heloderma* showing the poison groove.

ges in vegetation and temperature. The reptiles (living as well as extinct) are grouped into 17 orders. Of these orders, only four divergent orders are thriving today. These four orders are: *Rhynchocephalia*, *Squamata*, *Chelonia* and *Crocodilia*.

The order *Rhynchocephalia* is represented by its sole surviving member *Sphenodon* of New Zealand. The order *Squamata* includes the snakes and lizards. There are about 3,000 different species of lizards living today. More than 2,500 different species of snakes are found on earth. Some authors believe that snakes are the products of most recent reptilian development and they arose probably from lizards. Snakes with venom have not appeared before

Miocene. The order *Chelonia* includes the oldest living reptiles and embraces more than 200 species. The order *Crocodilia* was once enjoyed a very wide spread distribution but now includes only 25 species. The classification given below is based largely on the scheme adopted by Parker and Haswell.

CLASSIFICATION IN OUTLINE

CLASS **Reptilia**

Subclass Anapsida
  Order *Cotylosauria*, e.g., *Seymouria*, *Captorhinus*.
  Order *Chelonia*, e.g., Turtles and tortoises.

Subclass Ichthyopterygia
  Order *Mesosauria*, e.g., *Mesosaurs*.

Order *Icthyosauria*, e.g., *Icthysaurus*, *Ophthalmosaurus*.

Subclass Synaptosauria
Order *Protorosauria*, e.g., *Araescelis*.
Order *Sauropterygia*, e.g., *Placodus*, *Cyamodus*.

Subclass Lepidosauria
Order *Eusuchia*, e.g., *Youngina*.
Order *Rhynchocephalia*, e.g., *Sphenodon*.
Order *Squamata*
Suborder Lacertilia, e.g., Lizards.
Suborder Ophidia, e.g., Snakes.

Subclass Archosauria
Order *Thecodontia*, e.g., *Ornithosuchus*, *Phylosaurus*.
Order *Crocodilia* (or *Loricata*), e.g., *Crocodylus*, *Alligator*, *Gavial*.
Order *Pterosauria*, e.g., *Pteranodon*, *Pterodactylus*.
Order *Saurischia*, e.g., *Tyrannosaurus*, *Gorgosaurus*.
Order *Ornithischia*, e.g., *Iguanodon*, *Camptosaurus*.

Subclass Synapsida
Order *Polycosauria*, e.g., *Dimetrodon*, *Edaphosaurus*.
Order *Therapsida*, e.g., *Gnognathus*.
Order *Ictidosauria*, e.g., *Tritylodon*, *Bienotherium*.

Triassic periods. The characteristic features are: (1) the complete roofing of the skull and (2) flattened plate-like pelvis. The order includes two suborders: Captorhinomorpha and Diadectomorpha. Examples: *Seymouria*, *Captorhinus* and *Diadectes*.

Order *Chelonia*. The order Chelonia includes the turtles and tortoises. They have unusual appearance and are actually the "reptiles in boxes". The chelonians may be marine or fresh water forms. Some forms inhabit the marshy land. The body is more or less elliptical and dorsoventrally flattened. The body is encased by a convex dorsal shield called the *carapace* and a flat ventral plate designated as the *plastron*. The head, neck, tail and limbs can be retracted inside the encased body. The chelonians move slow on land, but the aquatic forms swim fast by the paddles. They can withstand prolonged starvation by reducing the metabolic activities.

The tail is short. The cloacal aperture is

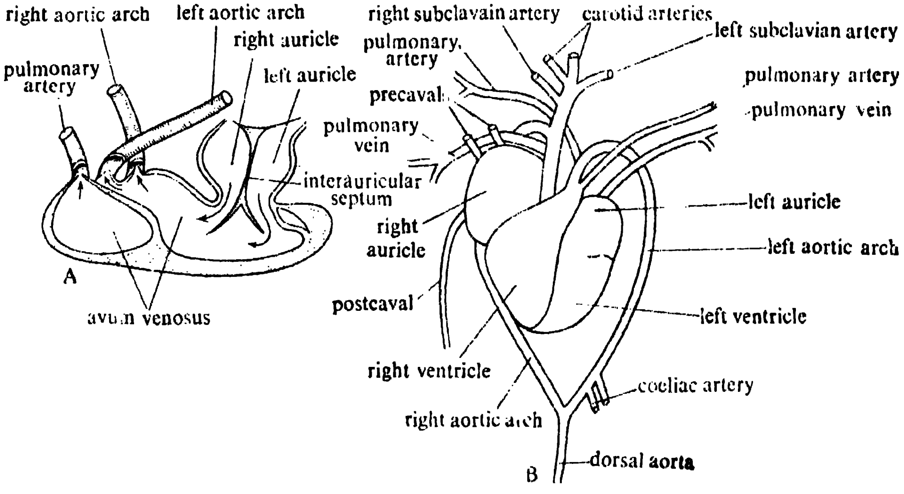

right aortic arch
left aortic arch
right auricle
pulmonary artery
left auricle
interauricular septum
A
avu.n venosus
right subclavain artery
carotid arteries
pulmonary, artery
precaval
pulmonary vein
right auricle
postcaval
right ventricle
right aortic arch
left subclavian artery
pulmonary artery
pulmonary vein
left auricle
left aortic arch
left ventricle
coeliac artery
dorsal aorta
B

Fig. 7.21. A. Diagrammatic longitudinal section of the heart of Chelonia. B. Main blood vessels of Chelonia.

CLASSIFICATION WITH CHARACTERS

The class Reptilia is divided into six subclasses. Most of the members are extinct and the living reptiles are represented only by a few divergent forms.

Subclass Anapsida

This subclass is characterised by the skull devoid of fossa behind the eyes The roof of the skull is solid. This subclass includes two orders: Cotylosauria and Chelonia.

Order *Cotylosauria*. All the members of the order are extinct and form the 'stem-reptiles' from which other reptiles have probably been evolved. They lived between Upper Carboniferous to Upper

longitudinal. Males possess a single median copulatory organ. The limbs are pentadactylous. The limbs may be modified into paddles in aquatic forms.

Teeth are absent in adult condition and the jaws are covered by horny pads. The gullet shows a great development. A long horny papilla points downwards which help in tearing food.

The ventricle is completely divided by the interventricular septum (Fig. 7.21A). Fig. 7.21B shows the position of main arteries and veins in Chelonia. Body temperature is not constant.

The nasal opening is single and anteriorly disposed. The lungs remain attached to the dorsal wall of the thorax and are invested with peritoneum on the ventral side only. Inspiration and expiration are done by movement of pectoral girdle and hyoid apparatus. The animals can suspend breathing for a considerable period. The vocal cords are absent.

In males the reproductive structures of each side lie close together. The penis is grooved and attached to the anterior wall of cloaca. Chelonians are oviparous and the eggs are provided with shell.

The skull is secondarily *anapsid* type (Fig. 7.22) and *monimostylic*, i.e., quadrate is immovably articulated to skull. All skull bones are firmly united to each other. A bony secondary palate is present which separates the nasal cavity from the mouth cavity. The occipital condyle is tripartite.

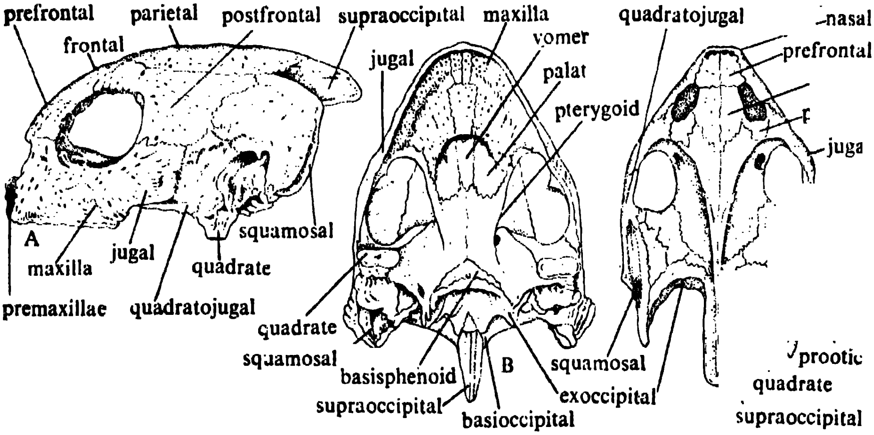


Fig. 7.22. A. Lateral view of the skull of *Chelone*. B. Ventral view of the skull of *Chelone*. C. Dorsal view of the skull of *Trionyx*.

The hyoid apparatus has a complex structural construction. The vertebrae are procoelous or amphicoelous. The cervical vertebrae are eight in number and are varied in regard to their articulating surfaces. The abdominal ribs are absent and the cervical ribs are rudimentary. The dorsal vertebrae are ten in number and lack transverse or articular processes. The ribs are fused with the carapace. Lumber vertebrae are absent and sacral vertebrae are two in number. The caudal vertebrae are few in number.

The sternum is absent. The pectoral girdle consists of a ventral *coracoid* and dorsal *scapula* attached to the carapace. From the scapula arises a large *precoracoid* (or *procoracoid*) which is ventrally directed. The scapular arch is internal to the ribs. The pelvic girdle consists of dorsally placed *ilia* attached to carapace. The *ischia* are posterior in position and the pubis is anterior in position. An epipubic cartilage is present. The pelvic symphysis is ischiopubic in nature.

Structure of Shell. The shell consists of dorsal *carapace* and ventral *plastron* and lateral bridges. The carapace is the upper part of the shell which covers the back and sides, plastron covers the belly and both of them are joined on each side by the bridge.

The shell is made up of two layers—an outer layer of horny shield or *dermal scutes* and an inner layer of *bony plates*. These two layers are broken up into sections that fit together like tiles. The sections of the horny plate is made up of 5 *vertebrals*, which form the central part, 8 *costals* arranged 4 in one side and round the vertebrals and a number of *marginals*. Of these marginals, two are called *nuchals*. The nuchals lie in the same line of the vertebrals and mark the beginning and the end of the central part. The inner bony layer is formed by the flattened neural spines which form the median pieces, expanded and fused ribs which are eight in number and are arranged as the median pieces and a series of marginals.

The outer layer of plastron consists of paired gular, humeral, pectoral, abdominal plates. Femoral and anal scutes are arranged along the anteroposterior axis and a number of marginal scutes is present. The inner layer is made up of nine bones and three anterior pieces which represent clavicles and interclavicles.

Examples:

Members belonging to the family Dermochelidae do not have bony carapace and the shells are leathery. These animals may measure about 2 meters and herbivorous in habit. Generally three claws are present on each foot. Sea-turtles belonging to the family Chelonidae are all marine and have paddle-like limbs and partially ossified carapace. *Chelone viridis* is in much demand as food. Tortoise shell is obtained commercially from *Eretmochelys imbricata.* Land tortoises belong to the family Testudonidae have perfectly ossified carapace and their feet are perfect to walk on land.

Subclass Icthyopterygia

The members of this subclass are all extinct. The roof of the skull was provided with an upper opening behind the eye and was bounded below by *postfrontal* and *supratemporal.* Two orders: Mesosauria and Icthyosauria are included under the subclass.

Order *Mesosauria.* They occurred in late Carboniferous or early Permian strata. They were aquatic in habit and lived in fresh water lakes. The body was slender and measured not more than a meter in length. The hind legs were much powerful than the front legs. The tail was laterally compressed. Example: *Mesosaurs.*

Order *Icthyosauria.* They occurred between middle Triassic and upper Cretaceous. They were marine and fish-like in appearance. Some were of considerable length measuring about 10–15 meters. Their skull had a single lateral vacuity. The head was large and produced into an elongated snout. The tail was long and limbs were in the form of paddles. The vertebrae were amphicoelous and cervical ribs were double headed. The sternum was lacking but abdominal ribs were present. Examples: *Icthyosaurus*, *Ophthalmosaurus.*

Subclass Synaptosauria

Late Palaeozoic and Mesozoic aquatic reptiles are included under the subclass. They possessed a single temporal (parapsid) fossa high in the skull. Synaptosauria includes two orders: *Protorosauria* and *Sauropterygia.*

Order *Protorosauria.* Existed during lower Permian. The reptiles were lizard-like in appearance not exceeding 30 cm in length. They were terrestrial and were very agile. The vertebrae were amphicoelous. Example: *Araescelis.*

Order *Sauropterygia.* Existed between Permian and Triassic strata. They were aquatic in habit. They had single temporal vacuity in skull which was bounded below by a postorbital. The squamosal and coracoid were single. The feet were webbed in some forms. There are three suborders under this order. Examples: *Placodus*, *Cyamodus.*

Subclass Lepidosauria

Representatives of this subclass have two temporal vacuities in the skull. In some specialised forms the vacuities have become reduced. This subclass embraces three orders: *Eusuchia*, *Rhynchocephalia* and *Squamata.*

Order *Eusuchia.* Lived in the upper Permian period. The skull had interparietal and tubular bones and parietal foramen. An orbital foramen was absent. Example: *Youngina.*

Order *Rhynchocephalia*

The order Rhynchocephalia is represented by a living representative, *Sphenodon.* Sphenodon is the oldest surviving lepidosaurian reptile and a Mesozoic fossil (*Homoeosaurus*) shows the continuity of the race. It is a living fossil and is popularly called the "Hatteria" or "Tuatara". Sphenodon was widespread in the main islands of New Zealand but is now restricted to some islets in the Bay of Plenty, North Islands. Due to the attacks of the wild pigs, dogs, cats, reptile-eating Maori tribes, the members of the genus, Sphenodon have been swept away in some small lone islands, where they can live safely. Very recently rigid conservative measures have allowed the genus to recover in number to a considerable extent.

Sphenodon is a timid animal which devours mainly on the insects. It lives in burrows and is nocturnal in habit. Sphenodon has a lizard-like body measuring about 70 cm in length. The body is dull olive green in colour with yellow spots above and whitish below. It weighs about 1 Kg. The tail is bilaterally compressed and crested. The tail can regenerate, if it is lost. The body is covered by small granular scales except the lower side where the scales form transverse rows of large square plates. A median row of erective spines ('frill') extends from the top of the head to the tip of the tail, but is interrupted at the neck region (Fig. 7.23A). The eyes are large, dark brown in colour with vertical pupil. The cloacal aperture is a transverse slit. The males lack copulatory organs.

The skull is typically built on the lepidosaurian plan. The skull is composed of paired premaxillae, nasals, frontals and parietals (Fig. 7.23B, C). A parietal foramen is present. Three temporal fossae are present. These are: (*a*) Supratemporal, situated behind the orbital fossa, (*b*) Infraorbital, located lateral to the supratemporal and (*c*) posttemporal, bounded by posttemporal bar. A fenestrated interorbital septum is present. Quadratojugal is ossified and quadrate is united to pterygoid, squamosal and quadratojugal. A vacuity is present between the median part of the pterygoids. An epipterygoid is present.

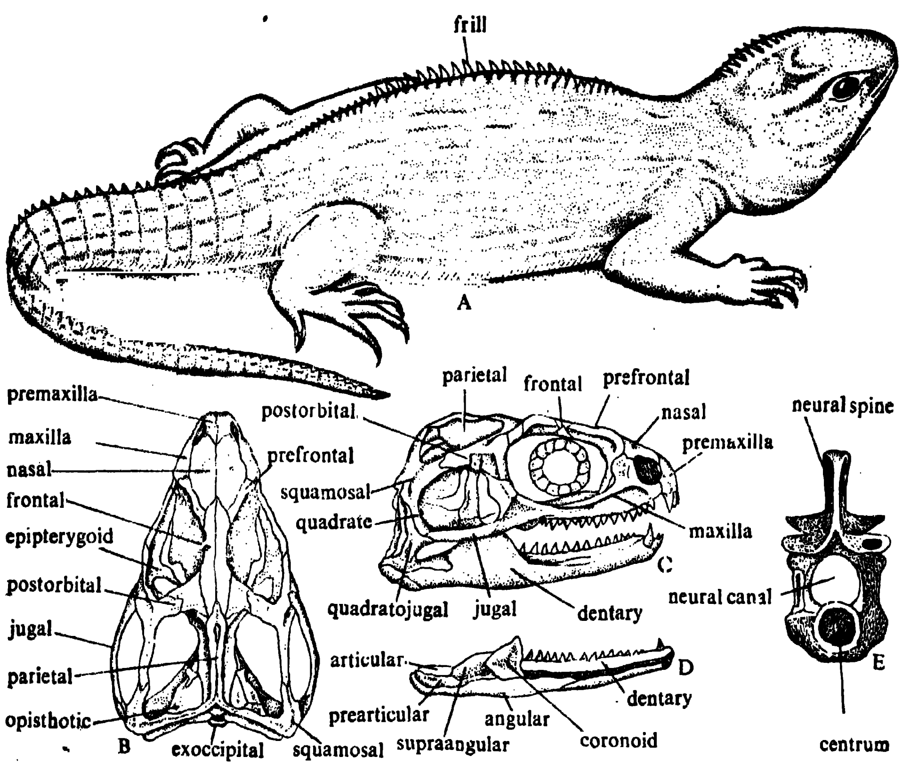

frill
A
premaxilla
maxilla
nasal
frontal
epipterygoid
postorbital
jugal
parietal
opisthotic
B
exoccipital
squamosal
postorbital
prefrontal
squamosal
quadrate
parietal
frontal
prefrontal
nasal
premaxilla
maxilla
C
quadratojugal
jugal
dentary
articular
prearticular
supraangular
angular
coronoid
dentary
D
neural spine
neural canal
E
centrum

Fig. 7.23. A. External structures of *Sphenodon*. B. Dorsal view of the skull of *Sphenodon*. C. Lateral view of the skull and lower jaw of *Sphenodon*. D. Lower jaw of *Sphenodon*. E. Vertebra of *Sphenodon*.

The rami of the lower jaw are united by ligament.

The vertebrae have amphicoelous centra (Fig. 7.23E) with persistent notochord. A so-called proatlas is present. Almost all the vertebrae possess chevron bone. The caudal vertebrae are divided by septum. The ribs are single headed, some of the ribs bear cartilaginous uncinate processes. First three ribs are represented by bands of connective tissue. Other ribs are bony. Abdominal ribs are present. A median sternum is present. The coracoids and interclavicle are attached at the anterior end. The interclavicle is 'T'-shaped and its lateral branches are fused with the clavicles. The coracoids lack fenestrae. The humerus bears both an ectepicondylar and an entipicondylar foramina. There are 10 or 11 pieces of separate carpal bones. The pubes are united by a symphysis. A cartilaginous epipubis is present. A large ischiopubic foramen is present between the ischium and pubis. A cartilaginous hypoischium is fixed to the ischia behind. The ilia are erect.

In Rhynchocephalia, the teeth are acrodont and are fused with the subsequent bone. A row of small triangular teeth is present on the maxilla and another set on the palatine. The mandibular teeth bite between the two rows on the upper jaw. The pterygoids are toothless. Vomerine teeth are present in young individuals. In Sphenodon, the teeth are replaced by pads.

The heart is typically reptilian, but the three main arches instead of emerging independently from the ventricle, come off by a short common trunk. The arterial and venous systems show certain interesting point of similarity with that of urodela. The brain is simple (Fig. 7.24A) with a very well-developed parietal organ (third eye). Much publicity has been given to the so-called third eye of Sphenodon. In young stage, its position is marked by a translucent scale over the skull. But in the adult, it becomes covered with skin. The third eye is made up of a lens, a retina with a nerve connected to the brain, but iris is absent (Fig. 7.24B). The actual role of the third eye is not ascertained. It shows a tendency towards degeneration. The life process is slower than that of other reptiles and the eggs take over a year to hatch.

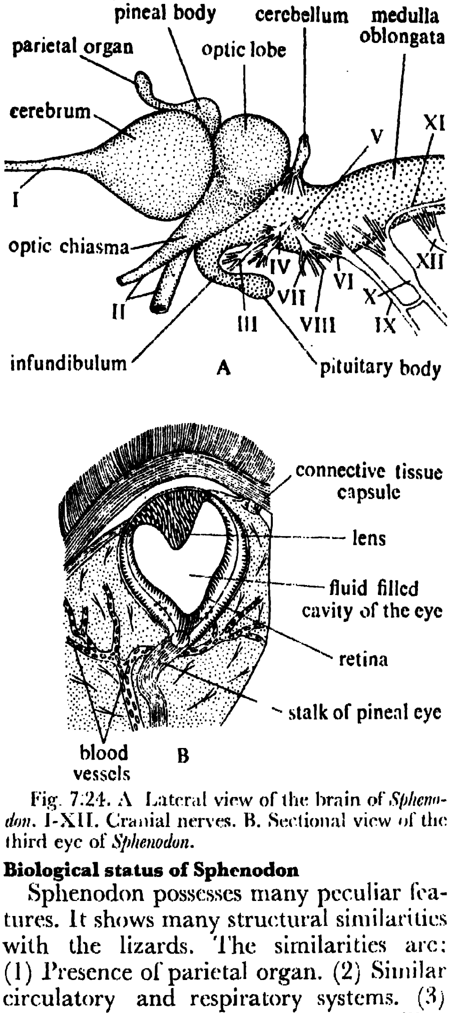


Fig. 7·24. A Lateral view of the brain of *Sphenodon*. I-XII. Cranial nerves. B. Sectional view of the third eye of *Sphenodon*.

Biological status of Sphenodon

Sphenodon possesses many peculiar features. It shows many structural similarities with the lizards. The similarities are: (1) Presence of parietal organ. (2) Similar circulatory and respiratory systems. (3) The skull is typically built on the lacertilian plan. (4) Amphicoelous vertebrae in Sphenodon and Gecko. But Sphenodon differs from the lizards by having (1) an extra vacuity in the skull, (2) immovable quadrate, (3) abdominal ribs and uncinate process, (4) ect-, and ent-epicondylar foramina in the humerus and (5) 10 bones in the carpus.

Sphenodon is a primitive form amongst the living reptiles. Absence of copulatory organs in males, forward extension of the pterygoid to meet the vomer (a feature recognisable in stegocephalians), emergence of the three main arterial arches from a short common trunk (probably representing the conus arteriosus of amphibian heart), retention of both ductus caroticus and ductus arteriosus are some of the characteristics which justify the primitiveness of Sphenodon amongst the surviving reptiles. It cannot be denied that Sphenodon approaches lacertilians more closely than any other groups of reptiles, but because of the retention of many peculiar individual characteristics its placement under a separate order Rhynchocephalia under the subclass Lepidosauria is thoroughly justified.

Order *Squamata*. The order Squamata includes the lizards and the snakes. This order possesses the following characters: (1) The skull bears superior temporal fossa. (2) The maxilla, palatine and pterygoid are immovably articulated with the skull, but the quadrate is movable. (3) Lower jaw is composed of several pieces of bones. (4) The teeth are either *acrodont* or *pleurodont* and are borne usually on the maxillae, premaxillae and palatines. (5) The vertebrae are of procoelous type. Chevron bones are present. (6) The ribs are single-headed. (6) The cloacal aperture is a transverse slit. (7) One pair of eversible copulatory sacs is present in males. (8) The brain is small. (9) Organ of Jacobson is well developed. (10) Distribution is cosmopolitan.

The Order Squamata has two suborders Lacertilia and Ophidia. The Lacertilia includes all the lizards, while the snakes constitute the suborder Ophidia. The lizards and snakes show many contrasting features which are tabularised in Table Chordata—11.

TABLE CHORDATA—11

Points	Lacertilia	Ophidia
1. Shape ..	Elongated body, usually with two pairs of limbs.	Cylindrical body without limbs.
2. Neck ..	Distinct.	Usually indistinct.
3. Limbs ..	Excepting the limbless lizards, the limbs are pentadactylus, each digit ending in a claw.	Secondarily lost. Vestiges of hindlimbs are present in Python.

Points	Lacertilia	Ophidia
4. Eyelids	Usually an upper and a lower eyelid are present. In the members of the families, Amphisbaenidae and Geckonidae the eyelids are fused over the eyes.	Absent and fused with the eyes. The eyes are protected by transparent scale covering the eyes as the spectacles.
5. Nictitating membrane	Movable except Amphisbaenidae.	Immovable.
6. Scales ..	Small and overlapping. Some forms develop osteoderms. May be modified into spines and 'frills' in many lizards.	Scales lack osteoderm. Exhibit regional differentiation—forming head shields, ventral shields, etc. The ventral scales are extremely large and transversely arranged.
7. Tympanum ..	Distinct.	Indistinct or absent.
8. Occipital condyle.	Single.	Distinctly triple.
9. Interorbital septum	Present except Amphisbaenidae.	Absent.
10. Fossae ..	Well-developed.	Absent secondarily.
11. Jugal ..	Present.	Absent.
12. Zygomatic arch	More or less complete.	Complete.
13. Epipterygoid ..	Usually present.	Absent.
14. Quadrate ..	Slightly movable.	Highly movable.
15. Interparietal foramen	Present.	Absent.
16. Basisphenoid ..	Not prolonged anteriorly into a rostrum.	Prolonged anteriorly into a rostrum.
17. Lower jaw ..	Rami are united firmly by bony symphysis. Each ramus is composed of six pieces of bones.	Rami are united loosely by ligament. Coronoid may be absent in some snakes.
18. Vertebral column	Differentiated into different regions, like cervical, thoracic, lumbar, sacral, etc. Vertebrae are procoelous except in Geckonidae where the vertebrae are amphicoelous.	Differentiated only into precaudal and caudal regions. Vertebrae are strongly procoelous with extra articulating points—zygantra and zygosphene.
19. Ribs ..	Restricted to some vertebrae.	Present in almost all the vertebrae except the atlas. Each rib is bifid distally and remain attached with the ventral scales by ligaments.
20. Teeth	Homodont, conical teeth—borne on the premaxillae, dentary and palatine.	Conical recurved teeth—borne by maxillae, palatine, pterygoid, dentary and very rarely by premaxillae. In poisonous snakes, the maxillary teeth become modified into fangs with opened or closed venom canal.
21. Lungs ..	Both are equally developed.	Left one is usually smaller or may be absent.
22. Arterial arches	Symmetrically disposed with ductus caroticus.	Asymmetrically placed without ductus caroticus.
23. Urinary bladder	Present.	Absent.
24. Brain ..	Cerebral hemispheres are short.	Extremely elongated and project in between the eyes.
25. Cranial nerves	12 pairs.	10 pairs.

Subclass Archosauria

Skull was of diapsid type and lacks interparietal and parietal foramina. Palatal teeth were lost in some forms. Some forms were toothless. The lower jaw was with vacuities between dentary and angular. In some forms bipedality was more marked and the girdles were modified accordingly. Order *Thecodontia* and Order *Crocodilia* are included under the subclass.

Order *Thecodontia*. They were present during Triassic period. Members belonging to the *suborder* Pseudosuchia under this order were small in size. They were carnivorous in nature. The teeth were sharp and were lodged in sockets along the jaw edges. The hind legs were long and indicated the dawn of bipedality. The members of the other *suborder* Phylosauria were aquatic. The skull was elongated. Array of holding and stabbing teeth were present on the jaws. The external nares were situated high above the skull level. Examples: *Orninthosuchus*, *Phylosaurus*.

Order *Crocodilia*

Among the major groups of reptiles, the order Crocodilia includes the largest forms of living reptiles. They are carnivorous and fresh-water reptiles. They swim by the undulation of their powerful tail. The limbs are not powerful as the tail but are used in carrying it on land. There are five digits in the forelimbs and four digits in the hindlimbs. The digits of the forelimbs are webbed. The body is elongated and the skin bears epidermal scales which are supported by dermal bones or scutes. The scales are supported by osteoderms. The tail is laterally compressed. The cloacal aperture is longitudinal. Males are provided single and median copulatory organ.

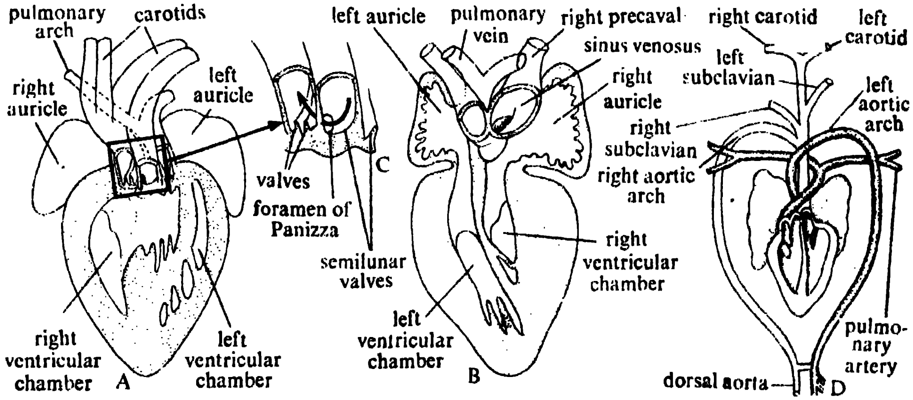

pulmonary arch
carotids
right auricle
left auricle
right ventricular chamber
A
left ventricular chamber
left auricle
valves
C
foramen of Panizza
semilunar valves
pulmonary vein
right precaval
sinus venosus
right auricle
right ventricular chamber
left ventricular chamber
B
right carotid
left carotid
left subclavian
left aortic arch
right subclavian
right aortic arch
pulmonary artery
dorsal aorta
D

Fig. 7.25. Heart of Crocodilia. (Longitudinal sectional view). A. Ventral view. B. Dorsal view. C. Showing the details of the foramen of Panizza. The arrow passes through the foramen. D. Diagrammatic view of the major blood vessels.

The teeth are thecodont and are borne on premaxillae, maxillae and dentaries. The teeth contain persistent pulp. The stomach suggests a bird's gizzard for the muscular walls are strong and pyloric end is twisted upward. Very often stones measuring about an inch in diameter are found inside stomach. The cavity of the mouth is bounded behind by two soft transverse membranes which meet when the animal draws the prey.

The nostrils are situated at the tip of the snout and can be closed by valves. The internal nasal aperture is situated at the back of the mouth. The lungs are invested by pleural sacs. An incipient diaphragm is situated between thoracic and abdominal wall. The heart (Fig. 7.25) is four chambered and the interventricular septum is complete. The roots of left and right aortic arches are communicated by the *foramen of Panizza* (Fig. 7.25C) through which an interchange of blood takes place. The crocodilians are poikilothermal animals. The brain is well-formed. The cerebellum shows the development of a median lobe (*vermis*) and two lateral lobes (*flocculi*). The eyes are provided with *pecten*. The nervous system and the sense organs show many avian features. The eggs are laid in excavated burrows and need no incubation. The skin glands are situated on the margin of lower jaw, round cloacal aperture and on dorsal scutes. Secretion of the glands smells like musk and becomes very strong during breeding season.

The skull is highly sculptured and sutures persist (Fig. 7.26). Interorbital septum with large alisphenoid is present. Maxillae, palatine and pterygoids meet at the middle line of the roof of the skull and determine the position of posterior nares. Transplantation bone is present. The quadrate is large and immovable. The interparietal foramen is absent. Internal nasal aperture is single. A bony secondary palate is present. Interorbital septum is well-developed. Teeth possess persistent pulp. Lower jaw is composed of a cartilaginous articular working on quadrate and five membrane bones.

The vertebral column is divisible into cervical, thoracic, lumbar, sacral and caudal regions. Vertebrae are procoelous excepting the first two cervicals, sacrals and first caudal. The caudal vertebrae are provided with chevron bones. Sternal and abdominal ribs are present. Sternal ribs have uncinate process. Most of the ribs are double headed. The pectoral girdle consists of dorsal scapulae and ventral coracoids. The clavicles are absent. The epicoracoids are thin strips between sternum and coracoid. The episternum is feebly developed. The coracoids are perforated. The pelvic girdle consists of large ilia, pubes and ischia. The epipubis is present and the symphysis is ischio-pubic in nature. The pubes are small and do not participate in the formation of the acetabulum.

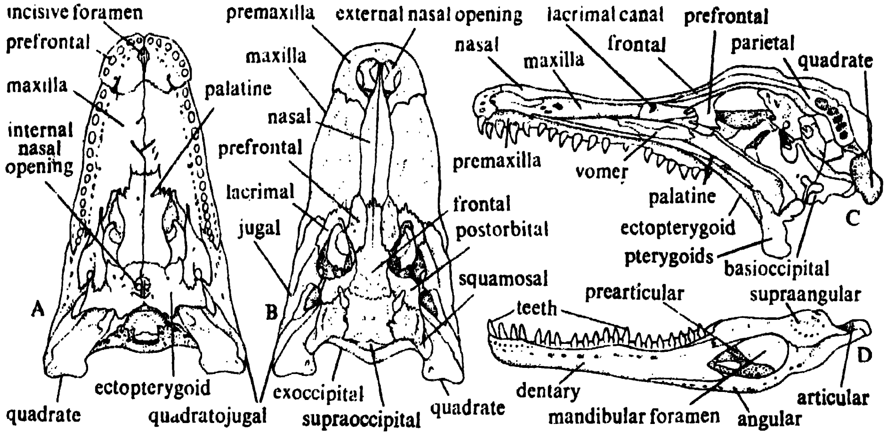

incisive foramen
prefrontal
maxilla
internal nasal opening
palatine
A
ectopterygoid
quadrate
quadratojugal
premaxilla
maxilla
nasal
prefrontal
lacrimal
jugal
B
exoccipital
supraoccipital
quadrate
external nasal opening
lacrimal canal
prefrontal
nasal
maxilla
frontal
parietal
quadrate
premaxilla
vomer
frontal
postorbital
squamosal
palatine
ectopterygoid
pterygoids
basioccipital
C
teeth
prearticular
supraangular
D
dentary
articular
mandibular foramen
angular

Fig. 7.26. Skull of *Alligator*. A. Ventral view. B. Dorsal view. C. Lateral view. D. Lateral view of the mandible.

The order Crocodilia is examplified by *Crocodylus*, *Alligator* and *Gavial*. These three forms are characterised by having individual characters which are shown in Table Chordata-12.

Order *Pterosauria* (*Pterodactyla*)

This order included the fossil flying reptiles. The bones were pneumatic like that of birds. The forelimbs became converted into wings. The fourth finger was greatly enlarged ("wing finger") to support the membranous wing. The fifth finger was lacking and the other fingers were small. The sternum was keeled. Examples: *Pteranodon*, *Pterodactylus*.

Order *Saurischia*

The members of this order were characterised by having triradiate pelvic girdle. Teeth were borne by the premaxillae. Examples: *Tyrannosaurus*, *Taleosaurus*, *Gorgosaurus*.

Order *Ornithischia*

The order Ornithischia included the 'bird-like' dinosaurs. The members of this order possessed a 'predentary' bone in the mandible which supports the beak. They were all herbivorous. Examples: *Iguanodon*, *Trachodon*, *Stegosaurus*, *Nodosaurus*.

Subclass Synapsida

They are considered as mammal-like reptiles. The skull was provided with a single and lateral temporal vacuity lying below the postorbital and squamosal. The supraoccipital was broad. The lower jaw was flat and the teeth were of heterodont type. The

TABLE CHORDATA-12

Points	Crocodylus	Alligator	Gavial
(1) Shape of the head ..	Elongated.	Blunt and broad.	Elongated and narrow.
(2) Teeth ..	Almost similar in size.	Slightly different.	Strictly similar.
(3) Mandibular symphysis	Extend upto 8th tooth.	Extend upto 8th tooth.	Extend upto 15th tooth.
(4) External nostril ..	Bounded mainly by premaxillae.	Bounded by premaxillae and partly by nasals.	Bounded only by the premaxillae.

shoulder girdles were with coracoids and precoracoids. The orders under the subclass are:

Order *Pelycosauria.* They existed between upper Carboniferous and lower Permian. The skull was with temporal vacuity. In forms, like *Dimetrodon*, the neural spines were much elongated. Some forms were carnivorous but majority were vegeterian. The limbs were short. Examples: *Dimetrodon, Edaphosaurus.*

Order *Therapsida.* They existed between middle Permian and lower Triassic. They constituted a very important group from the stand-point of evolution. According to Romer, they bridged the entire evolutionary gap between a primitive reptile and a mammal. In advanced therapsid reptiles, the occipital condyle was double. The temporal opening in the skull was big. The quadrate and quadratojugal were greatly reduced. In some forms, a secondary palate was present. The teeth were distinctly differentiated into the incisors, canines and molars. Examples: *Cynognathus, Lycosaurus.*

Order *Ictidosauria.* They existed between upper Triassic and middle Jurassic times. The temporal opening was large and confluent with the orbit. The quadrate and articular were reduced. Dentition was of heterodont type. Examples: *Tritylodon, Bienotherium.*

GENERAL NOTES ON REPTILES

HISTORY

The name reptiles was given with an eye to the snakes which crawl (*repere*=to crawl). That reptiles are familiar to man is evidenced from the fact that there are frequent mentioning of snakes, turtles or alligators in eastern and western mythologies. According to Hindu pantheon the the supreme God Vishnu had his third incarnation in the form of a turtle. Vashuki, a great snake on which the earth rests according to Hindu mythology, was used to churn the ocean to bring *Amrita*, a liquor for immortality. The snakes have been assigned an evil role in Judeo-Christian tradition. Adam was driven out of the Garden of Eden because of the temptation instigated by a serpent. Crocodiles and snakes are worshipped in Egypt. In Mexico a feathered serpent is the image of a fair God. Pliny and Galen in their time prescribed that to cure various ills vipers may be eaten. Viper tooth was much in use in Europe until very recently.

EVOLUTIONARY GAIN OF REPTILES

The evolutionary gain of the reptiles over the amphibians are the attainment of lungs and the development of embryonic envelops called the amnion and allantois. The reptiles and their descendants, the mammals and birds do not breathe by gills at any stage of their life but depend solely on lungs which are effective organs to derive oxygen from atmosphere. Again the reptiles and other conquerors of the land do not cradle their young ones in open water as do the amphibians and fishes. This has necessiated the formation of a protective antenatal robe round the growing embryo. The protective robe is the amnion, a thin enveloping sac filled with secreted watery fluid in which the embryo floats. The allantois, on the other hand, is an outgrowth from the posterior part of the digestive tract of the growing embryo. The amnion helps in withstanding exposure to dry air and mechanical shocks. Allantois is a richly vascular emergency organ which helps in respiration and excretion. Because of the presence of amnion the reptiles, birds and mammals are collectively called the *Amniota* while all the lower vertebrates in which no amnion develops are called *Anamnia.*

Other features that stand out sharply in reptiles are the presence of a thick integument covered with scales and lengthening and strengthening of limbs for locomotion on land. However, it cannot be denied that the name reptile was suggested with an eye to the limbless crawling snakes. But in reality the class Reptilia includes not only the snakes but also the lizards, turtles, tortoises, crocodiles as well as the living fossil, Sphenodon of New Zealand. The class Reptilia also includes a vast number of extinct forms that dominated the earth during Mesozoic era.

HABIT AND HABITAT

Tropical and subtropical regions of the globe are the most suitable abode of the reptilian fauna. The reptile population decline markedly towards the poles and high altitudes. Reptiles show adaptation to a variety of habitats. Turtles and snakes prefer to live in humid regions. Crocodiles live in swamps or rivers or along the sea coasts while large turtles live in the ocean. Land tortoises live on arid oceanic islands but box turtles are found in forests. Most of the lizards and snakes are terrestrial but some of them climb rocks and trees. Many lizards, like Geckos take shelter in crevices of rocks, trees and buildings. Some tropical reptiles, like Draco are arboreal and volant form. Black snakes often ascend trees in search of food. Snakes live in burrows dug by rodents but many lizards and snakes can dig burrows in sand with the rostral plate situated on the snout.

Since reptiles are cold blooded animals, fluctuation of environmental temperature influence them to a good extent. In tropical countries reptiles remain active throughout the year. In temperate countries reptiles remain active during day time. Reptiles living in the deserts or semi-desert regions show activity in the morning and late afternoon and always avoid the hot mid-day sun. Many desert snakes are nocturnal in habit. In cold seasons most reptiles undergo a period of dormancy. Lizards and snakes assemble in number in caves or burrows to hibernate Fresh water turtles go to the bottom of ponds.

SIZE

Some of the fossil reptiles were the largest terrestrial animals ever lived. They were more than 120 feet in length. Largest among the present day living lizards is the Komado dragon (*Varanus komodensis*) which is about 3 meters in length. Among the snakes *Anoconda* of South America attains a length of 10 meters. In contrast to that the size of the snake, Leptotyphlops of Syria is like that of a sewing needle. Some leather back turtles are 2.1 meters in length.

SKIN

Reptilian skin is dry and is covered by scales derived from the Malpighian layer of the skin. These scales are horny epidermal structures and are different in origin and structure from the bony dermal scales of fish. The scales vary greatly in form and size. These are small papilla like in Geckos and Chameleons. In lizards and snakes these are arranged in an imbricate fashion. Scales are large, horny and plate-like in tortoise. The scales often become modified in the form of crests and spines. In most reptiles the scales and the outer layer of the skin is shed periodically. The skin is shed as a whole by snakes, but in others, it is flaked off the body in small pieces.

Mucous glands which were so abundant in amphibians, are absent in reptiles. Glands derived from the mucous glands are restricted to some special parts of the body. The femoral glands of lizards and the glands on the throat and jaws of crocodiles are believed to be derived from the mucous glands. But the role of the glands has been changed. They are no longer used in keeping the body moist but are used as scent glands.

Many reptiles can change their colour due to threat, courtship or for concealment. For this purpose many reptiles contain pigment in the skin. In the dermis the pigments are present in distinct cells known as *melanophores* but in the epidermis the pigments remain scattered between the cells. The pigment cells function under the control of nervous system and in some forms remain under hormonal control.

SKELETON SYSTEM

Reptilian skeleton is strongly built with solid vertebral centra. The skull is hinged upon the atlas by a single occipital condyle. The skull bones are firmly ankylosed and are with vacuities. The mandible is made up of several pieces of bones. The teeth are simple, conical and have *acrodont*, *pleurodont* and *thecodont* types of attachment with the jaws. A pineal foramen is present in the roof of the skull. Vertebral column of the reptiles is divisible into 5 zones. Sacral vertebrae are usually two in number and caudal vertebrae bear chevron bones. Ribs are single headed and may be present on thoracic and abdominal regions. The sternum bears a minimum of two ribs. Pectoral and pelvic girdles are stout except in snakes and the limb bones are well developed.

Characteristic features of skull. A reptilian skull is characterised by the following: (1) Lack of cartilaginous elements. (2) Presence of a single occipital condyle. (3) Presence of a parietal and coronary sutures. (4) Presence of a parietal foramen in between the parietal sutures. (5) Presence of an interorbital septum except snakes and limbless lizards. (6) Presence of a rod-like epipterygoid bone between pterygoid and parietal. (7) Presence of ectopterygoid or transplatine between pterygoid and maxilla.

Besides these features, there are certain extra apertures or fossae in the reptilian skull. The whole classification of reptiles is based on the presence of these fossae.

Nomenclatures of Reptilian skull.

(A) **Anapsida.** Most primitive of the reptilian skull, in which the roof and the sides of the skull is entire, i.e., there is no fossa. Examples: *Seymouria* and chelonians.

(B) **Synapsida.** Skull with a pair of lateral or inferior fossae and situated beneath the junction of squamosal and postorbital involving the jugal. Example: *Therapsida.*

(C) **Parapsida.** Skull with dorsal openings or superior fossae, one on each side and above the junction of squamosal and postorbital infringing the parietal. Example: *Icthyosauria.*

(D) **Euryapsida.** Skull with a single fossa behind the eye and borded below by postorbital and squamosal. Example: *Protorosaurs.*

(E) **Diapsida.** Skull with both superior and inferior fossae. This type of skull is most specialised and most surviving reptiles possess diapsid type of skull.

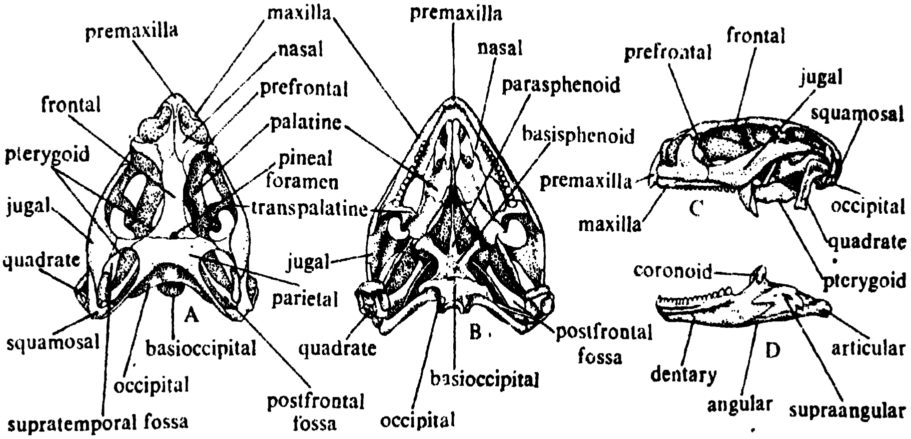

premaxilla
maxilla
nasal
prefrontal
palatine
pineal foramen
transpalatine
frontal
pterygoid
jugal
quadrate
squamosal
A
basioccipital
occipital
supratemporal fossa
jugal
parietal
quadrate
postfrontal fossa
occipital
premaxilla
nasal
parasphenoid
basisphenoid
B
basioccipital
postfrontal fossa
prefrontal
frontal
jugal
squamosal
premaxilla
maxilla
C
occipital
quadrate
pterygoid
coronoid
D
dentary
angular
articular
supraangular

Fig. 7.27. Skull of *Uromastix*. A. Dorsal view. B. Ventral view. C. Lateral view. D. Lateral view of the lower jaw (left half).

The transition of reptilian skull from primitive anapsid type to present day diapsid type stands in a good way in interpreting the evolution of reptiles. The primary purpose of the skull or brain box is to house and protect the brain. It also affords a platform for the attachment of muscles. In reptiles, the skull is not large as the brain itself is relatively small. The little increase in the size of the skull of reptiles is only for housing the muscles which work the lower jaw. This little increase has again been compensated by the formation of fossae or in other words reduction of part of skull bones. In reptilian skull, a happy compromise between strength and lightness and at the same time economy of material has occurred. Figs. 7.27 and 7.28 illustrate the skull of two lizards, *Uromastix* and *Varanus*.

Table Chordata 13 shows the nomenclature with characteristic features of reptilian skulls (after Parker and Haswell).

TABLE CHORDATA 13

Nomenclature	Number and position of fossa	Present in
Anapsid ..	None, solid roof of skull.	*Cotylosaurs*, Chelonians.
Synapsid ..	One, low behind the eye with postorbital and squamosal meeting above.	Pelycosaurians and Mammal-like reptiles.
Parapsid ..	One, high behind the eye with postfrontal and supratemporal meeting below.	*Mesosaurs* and *Icthyosaurs*.
Euryapsid ..	One, behind eye bordered below by postorbital and squamosal.	*Protorosaurs* and Sauropterygians.
Diapsid ..	Two, postorbital and squamosal usually meet between them.	Rhynchocephalia, Dinosaurs, Crocodilia, Lizards and Snakes.

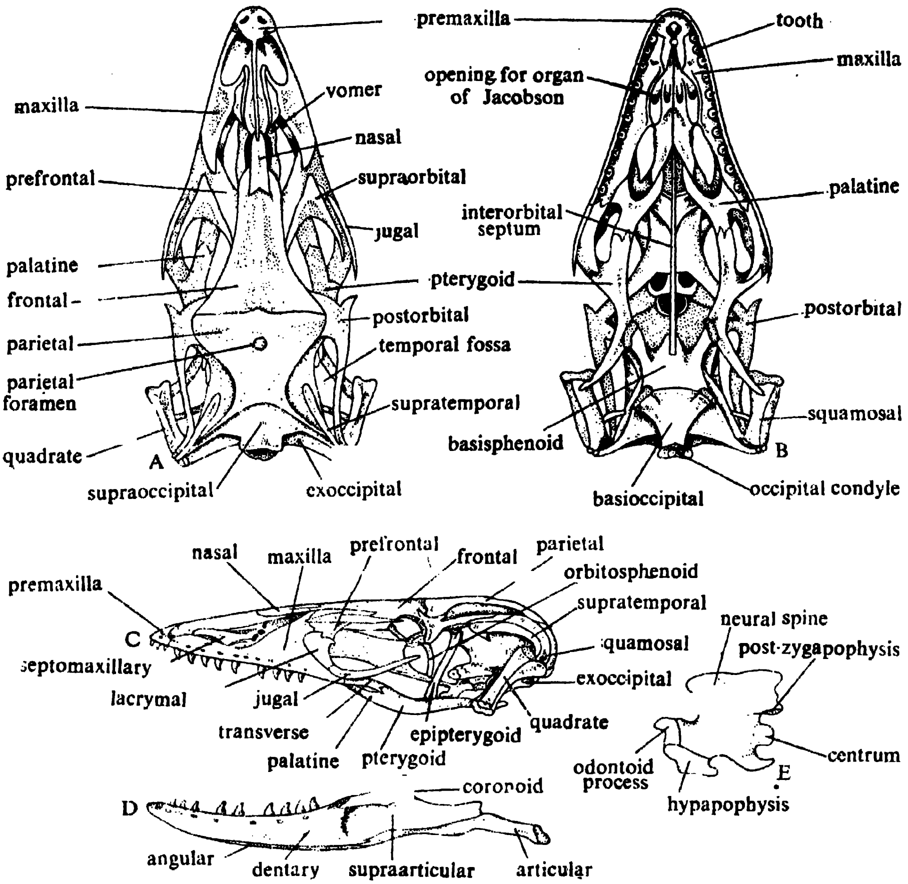

premaxilla
tooth
maxilla
vomer
opening for organ of Jacobson
maxilla
nasal
prefrontal
supraorbital
palatine
interorbital septum
jugal
palatine
pterygoid
frontal
postorbital
postorbital
parietal
temporal fossa
parietal foramen
supratemporal
squamosal
quadrate
A
basisphenoid
B
supraoccipital
exoccipital
basioccipital
occipital condyle
nasal
maxilla
prefrontal
frontal
parietal
premaxilla
orbitosphenoid
supratemporal
neural spine
C
squamosal
post-zygapophysis
septomaxillary
exoccipital
lacrymal
jugal
quadrate
transverse
epipterygoid
centrum
palatine
pterygoid
odontoid process
E
coronoid
D
hypapophysis
angular
dentary
supraarticular
articular

Fig. 7.28. Skull of *Varanus*. A. Dorsal view. B. Ventral view. D. Lateral view of the lower jaw (left half). E. Second vertebra of *Varanus*.

DIGESTIVE SYSTEM

Animals from fish to mammals constitute the food of most reptiles. Tortoise, turtles and some lizards like Chukwala and Iguanos of deserts feed on vegetation. The Iguanos of Galapagos dive deep into the sea to obtain marine algae for their food. The total intake of reptiles is small compared with that of birds and mammals.

Food is captured by teeth. The Chameleons capture their prey with the help of their elongated tongue. Nonpoisonous snake during food-getting coil round the body of the prey until the prey dies from asphyxiation. Poisonous snakes strike with their fangs to kill the prey by injecting venom.

Digestive canal begins in mouth and ends in anus. The edges of the jaws are provided with teeth. Teeth are present on some of the bones of the palate in some cases. The teeth are conical and recurved backwards. Teeth may be serrated or modified to form crushing pads. Fangs are modified teeth. Excepting the lizards, succession of teeth is a continuous process in all reptiles. The tongue is hardly movable in crocodiles but long, forked and highly movable in snakes. Salivary glands are present in majority of the reptiles. In some snakes and *Heloderma*, the upper labial glands become modified into poison glands.

The alimentary canal is typically of vertebrate type. The stomach is tubular, small intestine is rather short. The large intestine is wide and leads to a short caecum. The cloaca is subdivided into three chambers. The upper chamber or coprodaeum is meant for faeces. The middle chamber or urodaeum receives the ureters. The lower chamber is called proctodaeum which terminates in a cloacal sphincter. The division of the cloaca has become a necessity for the retention of water. It is believed that the coprodaeum and urodaeum reabsorp water from both the faeces and urine.

RESPIRATORY SYSTEM

External nares, internal nares, mouth cavity, glottis and larynx constitute the respiratory passage. The respiratory passage leads to a pair of lungs. The larynx is supported by cricoid and arytenoid cartilages. There occurs considerable variation in the structure of reptilian lungs. In Sphenodon lungs are like sacs, the wall of which bears small pockets lined with respiratory epithelium. In lizards and chelonians the lungs are provided with deeper pockets forming definite *alveoli*. In some lizards pockets assume long channels leading from the lung cavity to the wall of the lungs. In reptiles the wall of the lungs is provided with muscles which contract and expand rhythmically to assist in ventilation. The hinder part of the lung in many reptiles is smooth. The hinder part acts more a reservoir than a respiratory surface. In chameleons, the cavity of the lung is drawn outside the wall of the lungs to form air sacs like that of birds.

Though there occurs no significant respiratory activity through skin and epithelium of mouth in reptiles, yet it has been shown that in Trionyx, oxygen is taken up by the epithelium of pharynx. The urodaeal part of the cloaca has a paired diverticula in many turtles.These diverticula become filled and emptied rhythmically with water coming through the anus. These are regarded as the accessory respiratory structures.

In reptiles, expansion and contraction of the thorax by muscular activity draws air in and drives air out. The cycle of breathing in lizards is known. It consists of three phases. In the first phase there is an expiration. In the second phase there is an inspiration and in the third phase there is expiration. The glottis is held open during the cycle upto the end of inspiration. The air is driven out of the lung in the first expiration and sucked in during inspiration. The glottis remains closed during second expiration.

The cycle of breathing differs in various reptiles. In chelonia, because of the immovable carapace, expansion of the general wall of the thorax is difficult. But the lungs are expanded by the movement of head, limbs and girdles. In crocodiles, a septum across the abdominal cavity divides the abdominal cavity into anterior part housing the lungs and a posterior part containing the viscera. The septum is not muscular and probably has no role in the respiratory mechanism and as such it cannot be regarded as homologous with the mammalian diaphragm.

CIRCULATORY SYSTEM

Heart. The reptilian heart consists of two distinct auricles and a ventricle which is internally divided by an interventricular septum into left and right portions. In chelonia, snakes and lizards the septum is well-developed but does not close off the left hand portion of the ventricle from the right hand portion. The left hand portion is larger than the right hand portion. The left portion is further divided imperfectly into a *cavum venosum* to the right and a *cavum arteriosum* to the left by septum. This secondary septum is formed by the fusion of trabeculae. In crocodiles the cavity of the ventricle is completely divided into left and right portions. The right and left systemic arches cross each other in crocodiles and at the point of contact of the wall of the left and right systemic arches, there is an aperture called the foramen of Panizza. This foramen places their cavities in communication and allows admixture of oxygenated and deoxygenated types of blood.

The conus arteriosus is absent in reptiles and the arterial arches arise directly from the ventricle. Sinus venosus has shown a tendency to become fused with the right auricle in varying degrees. Excepting in Sphenodon the presence of sinus venosus is not distinguishable.

The right auricle receives venous blood from the body and the left auricle receives oxygenated blood coming from lungs. The cavity inside the right ventricle is known as *cavum pulmonale*. From the cavum pulmonale arises the pulmonary artery and from the cavum venosum originates the left and right aortic arches.

The contraction of the auricles pours venous blood from the right auricle into the cavum venosum and arterial blood from the left auricle into the cavum arteriosum. The cavum pulmonale becomes filled with venous blood and some amount of this venous blood overflows into the cavum arteriosum past the edges of the incomplete interventricular septum. When the ventricle contracts the lip of the interventricular septum touches the ventricular wall above and thus the cavum pulmonale is cut off from the rest of the ventricle. With further contraction of the ventricle the venous blood of cavum pulmonale is forced to go to the lungs through the pulmonary artery. The remaining portion of the blood in ventricle is mixed in nature because it contains both arterial and venous blood. This mixed blood with the contraction of the ventricle passes out through the aorta. The root of the left and right aortae inside the ventricle is so oriented that the right arch receives mostly the arterial blood and the left arch receives mixed blood. Thus the mechanism of circulation of blood from the heart in reptiles is so designed that even in the absence of anatomical division of the ventricle there has occurred a physiological separation of oxygenated and deoxygenated blood.

Arterial system. Of the six pairs of embryonic arterial arches, the 3rd, 4th and 6th pairs are retained in reptiles. The 5th arch is present in reduced form in some reptiles. The remnant of the radix of aorta between 3rd and 4th arches is present on each side in some snakes.

The conus arteriosus is splitted into three vessels. The fourth arch on the left side arises from the right side of the partially divided ventricle. The fourth arch on the left side becomes the left aortic arch The fourth arch on the right side arises from the left side of the ventricle. It establishes a connection with a portion of the radix of aorta of the right side and becomes the right aortic arch. The common carotid arch rises from the right aortic arch and becomes divided into external and internal carotid arteries. The 6th aortic arch loses all its connection with radices of aorta and becomes the pulmonary arteries.

The radix of aorta between carotid and systemic arches is present as *ductus caroticus* in many lizards. Similarly a part of the radix may remain connected with the 6th aortic arch. This connecting part is known as *ductus arteriosus* or *ductus Botalli*. Ductus caroticus and ductus arteriosus are both present in Sphenodon.

Venous system. The venous system in reptiles shows little advancement over that of amphibians. Two precavals and one postcaval open into the sinus venosus which itself shows a tendency towards fusion with the right part of the auricle. Anterior abdominal vein is prominent in reptiles and more blood passes through it from the posterior part of the body. The renal portal system loses its importance to some extent.

NERVOUS SYSTEM AND SENSE ORGANS

The central nervous system or brain in reptiles shows a better developed condition than the amphibians. In reptiles the cerebellum and the cerebral hemispheres are more developed than the amphibians. The cerebellum is enlarged and this enlargement is most prominent in chelonians and lizards. The cerebral hemispheres exhibit enlargement of palaeopallium and archipallium. The cells of these two parts of the pallium are shifted in reptiles towards the surface so as to show the beginning of cerebral cortex formation which is recognised in mammals. In some reptiles a new structure called *neopallium* has appeared between the archi- and palaeopallium. This new structure is absent in Sphenodon. The diencephalon houses several organs of special interest. These organs include the large hypophysis and the parietal organ. The hypophysis is differentiated into an anterior and a posterior lobe.

The parietal organ extends to the dorsal surface of the skull and forms the pineal or parietal eye. The parietal eye is well developed in Sphenodon. The optic and olfactory lobes are some what reduced.

Eye. The eyes of reptiles are variable in structure and adaptation. Among the reptiles the eyes of lizards are best developed. The eyes of the snakes are greatly modified because of their nocturnal and burrowing habit. On the cornea of the reptiles, a transparent covering formed by the fusion of the eyelids is present. The eyes of crocodiles have undergone modification due to nocturnal and aquatic adaptation. The eyes of turtles and Sphenodon are primitive in structure than that of lizards.

Ear. The tympanum, when present, lies at the back of the jaws. In the inner ear, lagena has become longer. It has got on its inner wall a group of sense cells called basilar papillae which form the centre for auditory appreciation. All the organs of the inner ear are housed in a perilymph cistern. This cistern has been formed by the tubular extension of the perilymph system.

It has been shown that the ears of certain tortoises are sensitive to sound wave, a range of 110 cycles per second. The sense of hearing is best developed in crocodiles and lizards amongst the reptiles.

Other sense organs

Sense organs for touch, pain and temperature are situated in the skin of reptiles. Organ of Jacobson is situated on the roof of the mouth and close to the internal nares. It is chemoreceptor in nature. Sensory epithelium is restricted on the dorsal part of the nasal chamber. Beginning of the turbinals are witnessed in the outgrowths from the wall of the dorsal part of the nasal chamber.

EXCRETORY SYSTEM

The functional excretory organs are the metanephric kidneys. The shape of the kidneys in different reptiles is variable. In lizards and crocodiles the kidneys are much elongated and are housed in the posterior part of the body cavity. In snakes the kidneys are long, slender and the position of the kidneys in the body cavity is asymmetrical, i.e., one kidney is located above its counterpart on the other side. In turtles, the kidneys are more compact than in other groups. The posterior ends of the kidney show a tendency of fusion in many lizards. The glomeruli inside the kidneys are reduced in reptiles.

The excretory ducts or ureters discharge their contents directly and separately into the cloaca. In male lizards the ureters unite with the vasa deferentia and open jointly in the cloaca. In turtles and many lizards, an urinary bladder is present. The ureters open in these cases into the urinary bladder. The urinary bladder is allantoic in origin.

In terrestrial reptiles the final product excreted as uric acid. The final excretory product is a chalky white mass of urates and it is almost dry. The dryness is due to reabsorption of water in the urodaeum. In lizards and snakes, 80 98% of the excretory product is the uric acid. In aquatic turtles the excretory product contains little of uric acid and much of urea. In crocodiles and aquatic snakes upto 75% of the excretory product comprises of ammonia.

REPRODUCTIVE SYSTEM

In reptiles the sexes are separate. Sexual differences are not easy to find out from external appearance. In some forms sexual colouration marks off the males from the females. The general tendency exhibited by the reptiles in their reproductive system is that excretory and reproductive systems have become separated excepting their common opening into the cloaca. Because of the shape of the body the disposition of the left and right gonads in both males and females has become assymetrical in some forms and specially in snakes.

Fertilization is internal in reptiles. All modern male reptiles (excepting Sphenodon) possess copulatory organs. These intromittent organs are derived from the wall of the urodaeum of the cloaca. In crocodiles and tortoises, there is a single penis which is median in position but in lizards and snakes there is a pair of these structures laterally placed in the cloaca. They are called hemipenes. Out of these two, one is inserted at a time. Muscular action and vascular engagement causes erection.

Oviparous reptiles lay their eggs on land. For physical support and protection against dessication, the eggs are provided with shell secreted by the wall of the oviduct. For adequate supply of food during embryonic development a large quantity of yolk is present inside the eggs. Special embryonic membranes known as amnion and allantois look after gaseous exchange and storage of waste product. Egg albumen or egg white is present to a considerable amount in crocodiles and tortoises but in snakes and lizards the quantity of albumen present is very poor.

Many snakes and lizards are ovoviviparous. In forms like *Lacerta vivipara*, *Anguis fragilis* and *Vipera berus*, the eggs are retained within the oviduct till the youngs are ready or nearly ready to hatch. The eggs of ovoviviparous reptiles have the shell reduced to a membrane. In sea snakes and certain lizards a placenta developed from the chorioallantois or the yolk sac or both. The placenta serves for gaseous exchange and transfer of water. It is believed that in some advanced forms, the placenta provides a mean for food supply.

To come out from the egg shells young reptiles have egg tooth. In Chelonia, Sphenodon and Crocodiles the egg tooth is present on the snout. In Squamata, a true egg tooth is present which projects from the front of the upper jaw. Egg tooth is rudimentary in ovoviviparous forms.

Maternal care or paternal care is not very deep in reptiles. Some reptiles abandon the newly laid eggs. Female python and certain snakes and lizards exhibit *little maternal* care by broading their eggs. Female alligators guard their nests.

EXTINCT REPTILES

Reptiles originated from stegocephalian lineage during the Carboniferous time and enjoyed golden days till the end of Mesozoic. Palaentological records show that no fewer than fifteen orders of reptiles existed, of which only four orders have representatives living today. In fact, the fossil remains of extinct reptiles present a dramatic chapter of rise and fall of reptilian dynasty which lasted according to some geologists from 125 to 150 million years.

The mesozoic era has been called the "Golden age of reptiles". The reptiles ruled and dominated the earth during the era though the birds and mammals made their humble appearance at that time. So insignificant mammals and birds were in those days that they never disputed with "reptilian horde for a place under the sun".

The mesozoic reptiles attained great diversity of form in those days and some became about 130 feet in height, i.e., they became giant among the animals that ever existed on earth. These reptiles exhibited wide range of adaptive radiation and mastered the various habitats which the wide world displays.

Some of the illustrious and strange members of extinct reptiles of the pre-camera days are outlined below:

Cotylosaurs. They are considered as stem-reptiles and as primitive members of the class. Externally they were large lizards-like and structurally they were very close to primitive Amphibians.

Therapsids. Therapsids had teeth differentiated into incisors, canines and molars. The attachment of jaw showed a tendency towards mammalian plan. They are believed to be ancestral to mammals.

Pelycosauria or fin-back reptiles. Among certain genera of this order, the spinous processes of the vertebrae did grow to an enormous size and gave them fin-backed forms as in *Edaphosaurus.*

Icthyosaurs. They were aquatic reptiles. In general appearance, they were fish-like having their paired appendages modified into flippers. A number of fossil specimens with small and complete skeleton inside their bodies have been found. This fact suggests that Icthyosaurs were viviparous.

Pterosaurs. They were flying reptiles. The fourth digit of the forelimbs of these animals became strong and elongated. The wing which was nothing but a fold of skin was supported by this elongated digit. Many palaeonlogists believe that they used to glide and were not truely flying in habit.

Dinosaurs. The stars amongst the extinct reptiles were undoubtedly the Dinosaurs and the age of reptiles often is called as the age of Dinosaurs. From the middle of Triassic to the end of Cretaceous, these Dinosaurs dominated the earth. Distribution of Dinosaurs was world-wide and their fossil remains have been found in all parts of the globe excepting New Zealand.

The appearance of the Dinosaurs varied widely and in size they ranged from tiny to enormous forms. The minimum recorded size was that of *Compsognathus* which was about two and half feet while the maximum recorded size was that of *Gigantosaurus* which reached a length of eighty feet and weighed about forty tons.

Many of these Dinosaurs were biped and could raise themselves up on their hind legs for rapid running. The forelimbs were shorter than the hindlimbs and it is believed that these were used during rest and slow walking. The tail of these reptiles was long, massive and heavy which could counter balance the body during rapid running like a third leg. The body of the Dinosaurs was scaly or heavily armoured and some had horns and beaks.

The eggs of the Dinosaurs were large and majority of them were viviparous. In food habit, the Dinosaurs were either carnivorous or herbivorous. The carnivorous Dinosaurs had strong dentition and they used to prey upon small to large creatures. Teeth were reduced in Diplodocus and Stegosaurus while Struthiominus had no teeth. Many of the Dinosaurs developed amphibious habits and used to spend their time to swamps.

The Dinosaurs had a majestic rise and a dramatic fall and the extinction of this mighty race which underwent an explosive evolution is still a matter difficult to explain. It has been conjectured that inter-specific warfare amongst the Dinosaurs themselves or destructive slaughter of youngs by blood-thirsty mammals or change in climate led to the extinction of Dinosaurs.

SUMMARY

1. Reptiles are the first true terrestrial vertebrates.
2. They dominated the earth during Mesozoic time. But many forms have become extinct now.
3. Living reptiles of today are represented by *Sphenodon*, lizards and snakes, chelonians and crocodiles.
4. Reptiles have given up the habit of breathing by gills at any stage of their lives and have the lungs as respiratory organs.
6. Development of antenatal robe in the form of amnion and allantois in the embryonic stage to protect the developing embryos is unique in them.
7. The skin is thick and covered with scales.
8. For locomotion on land the limbs have become longer and stronger to carry the weight of the body.
9. An interventricular septum divides the ventricle partly into left and right portion.
10. Body temperature in reptiles is not constant.
11. The kidneys are of metanephric type and the urinary bladder, when present, is allantoic in origin.
12. Males are mostly provided with intromittent organs derived from the walls of the urodaeum part of the cloaca.
13. The brain is well-developed with commissures and connectives. Presence of aberrant commissure is very characteristic.
14. Sense organs are well-developed and organ of Jacobson is present.
15. Many snakes have poison glands.

Phylum chordata—BIRDS

Birds are included under the class Aves. They constitute a highly specialised group of vertebrates which have attained the peak of evolutionary perfection. Birds are 'heavier-than-air' machines and almost every part of their body has been modified for aerial life. Because of their adaptation for flight in air, the members of the class exhibit less diversity of structures (Fig. 8.1) in comparison to that of other vertebrate classes. They are essentially 'glorified reptiles' and the discovery of the fossil of *Archaeopteryx*, unequivocally speaks about the reptilian origin of birds. This chapter deals with the biology of the class Aves with a special emphasis on their phylogenetic relationship with the reptiles.

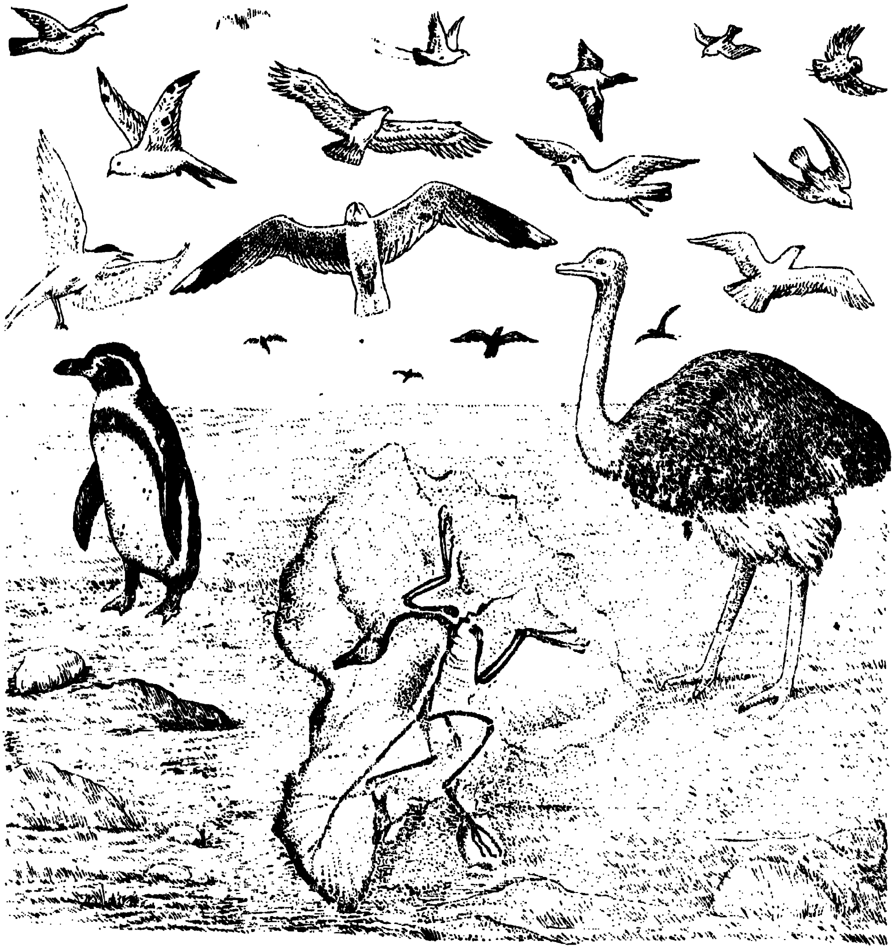


Fig. 8.1. Birds are unique by having their body covered by feathers. They have conquered the air by making significant modifications in their body form. They are also noted for their less diversity in their structures. The discovery of fossil, 'Archaeopteryx' speaks of the reptilian ancestry of birds.

IMPORTANT FEATURES

Birds are characterised by having the following features: (1) Body is covered by special integumentary derivatives called *feathers*. Feathers, while clothing the body, also form the surface of wings and tail.

The feathery covering makes the body light and at the same time protects from the hazards of temperature. (2) Body is spindle-shaped and thus offer least resistance during flight. (3) Anterior part of the body is concerned with flight and the movement on land is carried by posterior half. (4) Body is considerably light due to the presence of air-sacs and pneumacity of bones. (5) Several organs are either reduced or absent. Heavier organs are centrally located and near the wings. (6) Forelimbs are modified as wings and have powerful flight muscles. (7) Skeletal system is greatly modified to assist in both flying and perching. Fusion is marked in number of places to offer rigidity and reduces mechanical friction. (8) Head is small and placed on a fairly long movable neck. Mouth is provided with specialised exoskeletal derivative called beaks and are without teeth. Absence of teeth has made the skull light. (9) Alimentary canal contains a specialised structure called the gizzard for the crushing of food. The gizzard is complex in grain eating birds, but in fish-eating (piscivorous) forms it is simple. The canal is reduced in length and not much coiled. (10) Respiratory system is specialised to perform *double respiration*. Lungs are elastic and fixed on the dorsal wall of the thorax. Special air-filled sacs are present. Sound-producing organ is called syrinx. (11) Heart is four chambered and there is a complete separation of oxygenated and deoxygenated blood. Sinus venosus and conus arteriosus are absent. Single aortic arch turns to the right side. Red blood corpuscles are elliptical and nucleated. (12) Body temperature does not change with the change of environmental temperature. For this reason birds are called warm-blooded or homeothermal animals. (13) Excretory organs are metanephric kidneys and excretory ducts are free from carrying the products of genital organs. The urine is semisolid. (14) Nervous system includes well-developed brain and sense organs. Eyes are usually powerful and a specialised structure called pecten is present inside the eye-ball to help in accomodation. (15) Oviparous and development requires specific temperature. Usually both the sexes sit alternately over the eggs and provide the required temperature for incubation. (16) Eggs contain much yolk and segmentation is meroblastic.

OUTLINE CLASSIFICATION

Nearly 12,000 species of birds are known to be present throughout the world. The proper classification of birds has been hindered by two factors — (1) Absence of adequate number of fossil forms and (2) Presence of close similarity between the living forms. The class is subdivided into two subclasses *Archaeornithes* and *Neornithes*. The subclass Archaeornithes includes the fossil bird, *Archaeopteryx*. The subclass Neornithes consists of four superorders: *Odontognathae* (extinct Cretaceous birds), *Palaeognathae* (running birds). *Impennae* (penguins) and *Neognathae* (flying birds). Neognathae includes 22 orders, of which the order Passeriformes has the largest number of species.

EXAMPLE OF AVES COLUMBA

The pigeons are known both as wild and domesticated forms. They exhibit most of the peculiar characters of birds and are available in large numbers. They are scientifically known as *Columba livia domestica* and belong to the order Columbiformes. The other pigeons are wood pigeons (*Columba palumbus*), stock dove (*Columba oenas*), parrot pigeons (*Tereon abyssinica*), crowned pigeons (*Coura sp.*) and tooth-billed pigeon (*Didunculus strigirostris*).

HABIT AND HABITAT

The pigeons are seen almost throughout the world, specially in tropical and temperate zones. Both the wild and domesticated forms exhibit social behaviour. They fly in flocks and roost together. Usually these birds start the day with a chorous of humming notes. In the morning and afternoon, entire flock fly to search food and water. Pigeons drink water by drawing long draughts. Such drinking is unusual in other birds, which usually sip water. It returns to its perching place during the hottest part of the day and retire at night. Most pigeons are grain or seed eaters and swallow the entire grain. Fighting rarely occurs, though threatening posture during mating season is often displayed. The pigeons are monogamous and partnership lasts for entire life. Nest building commences after courtship. The pigeon's nest appears to be crude and disorderly arranged but is tough enough to face the hazards of wind and rain. Each clutch includes two bluish white eggs and the parents alternately sit over the eggs. Such incubation continues for seventeen days. Newly hatched nestlings are helpless, blind and without feathers. The parents provide them first with a special kind of "milk" and then with partly digested seeds and grains. The feathers appear after 10th day of hatching but the young pigeons continue to stay for a month with the parents.

EXTERNAL STRUCTURES

The size varies from 20-25 cm. The appearance varies in different varieties but all of them have a compact and more or less spindle-shaped body (Fig. 8.2). The body is distinctly divisible into three regions, *head*, *neck* and *trunk*. Most part of the body is covered by feathers, which are integumentary derivatives.

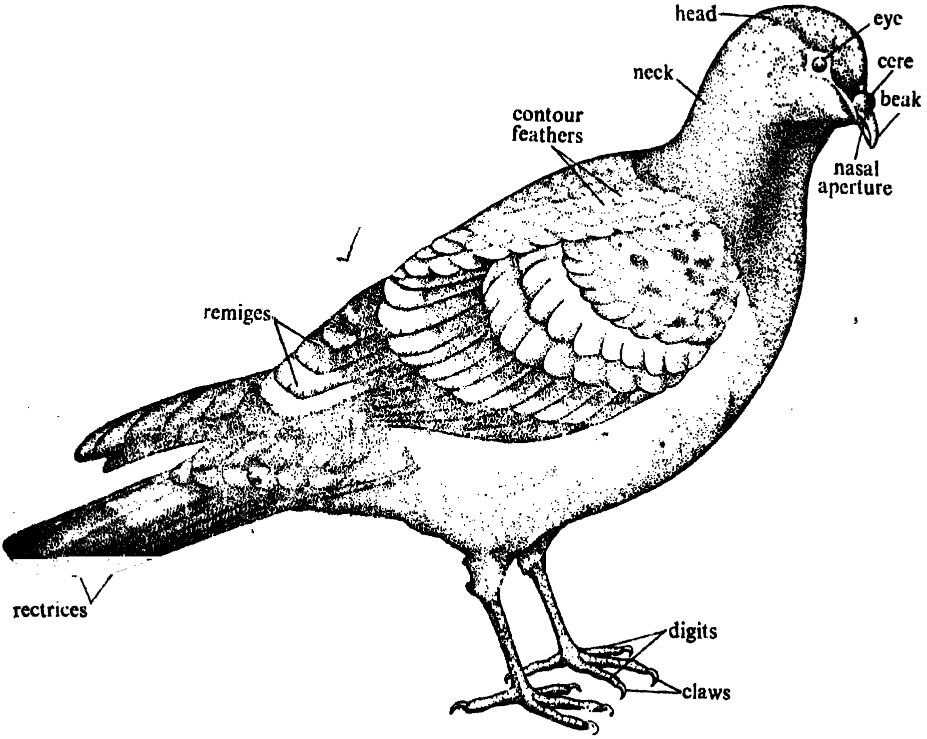


Fig. 8.2. External structures of *Columba*.

The head is small, round and anteriorly pointed. It contains the following structures; (*i*) *Mouth*. It is a wide gap at the anterior end of head and bounded by upper and lower beaks. Both the beaks are covered by a sheath called horny sheaths or *rhamphothecae*. The two beaks are pointed, hard and suitable for its grain-eating habit. (*ii*) *Cere*. Near the base of the upper beak a pair of swollen, feather covered areas, called cere is present. Just anterior to the cere, a pair of external nares is present as minute slits. (*iii*) *Eyes*. On each lateral side of the head, a prominent eye is placed. Each eye is provided with an upper, a lower and a movable transparent third eyelid or *nictitating membrane*, which runs across the eye-ball. (*iv*) *External ear*. These small paired apertures are present one on each lateral side of the head and slightly posterior to the eye. Each aperture remains covered by a special group of feathers called *auricular feathers*. Each aperture leads into a canal called the *external auditory meatus*.

The neck is long and flexible. It holds the head over the trunk and its flexible nature is responsible for the universal movement of head.

The trunk is compact stout and immovable. All the heavier organs are placed on the central part of the trunk and immediately beneath the wings. The trunk region contains following **structures**: (*i*) ***Forelimbs***.

Paired forelimbs are connected with the anterior region of the trunk and are greatly modified as *wings*. At the time of rest, the wings lie on the lateral side of the trunk as a folded 'Z'. Each wing has three divisions, *upper arm*, *fore arm* and *hand*. Folds of skin extend between upper arm and trunk and also between upper arm and fore arm. The former fold is called *postpatagium* and the latter is known as *prepatagium*. Both the patagia are greatly reduced. The portion of hand is tightly packed by a fold of skin and each has three clawless insignificant digits. (*ii*) *Hindlimbs*. Paired hindlimbs work as legs and are modified to carry the entire weight of the body during perching and walking on land. It is connected with the trunk near its posteriolateral side. The thigh portion of the hindlimb runs parallel to the body and during rest remains under the cover of the wings. Each hindlimb is provided with four toes of which the first one is called *hallux* which is directed backwards and the remaining three are pointed anteriorly. The upper part of the hindlimb is feathered but the lower part is covered by *scales*. All the toes are provided with sharp and pointed *claws*. At the time of flight, the hindlimbs are kept withdrawn and are released like the wheels of an aeroplane immediately before landing. (*iii*) *Tail*. Posteriormost conical end of the trunk is known as *uropygium*. On the ventral side of the uropygium lies transverse slit called the *vent* or *cloacal aperture*, which serves as the outlet of cloaca. On the middorsal region of the uropygium there is a gland called *uropygial* or *preen* or *oil gland*. This gland produces an oily secretion, which is drawn by the beaks and sprayed all over the body. The uropygium has special series of feathers called rectrices. These feathers in the uropygium constitute the tail of pigeon. The tail is used as steering and brake during flight and works as balancing organ during walking or perching or flying.

SKIN

The skin of pigeon is dry, thin and loose in texture. Skin glands are absent. The uropygial gland is the only integumentary gland. All over the skin numerous free nerve endings remain scattered. Near the base of the upper beak these nerve endings form specialised organ for touch in the cere. In spite of its thin appearance, the skin has the great ability to produce keratin, which is used largely in the formation of various integumentary derivatives.

SKELETAL STRUCTURES

Pigeon possesses well-formed exoskeletal and endoskeletal structures.

Exoskeleton

Following integumentary structures are seen in birds which perform different functions. (*i*) **Beaks.** These are horny exoskeletal derivatives which cover the upper and lower jaws. It is used during ingestion, preening of feathers and fighting. (*ii*) **Claws.** These are pointed, sharp and horny exoskeletal organs which are present at the extremities of the toes. The claws are typically reptilian in construction and help during perching and walking. (*iii*) **Scales.** These reptile-like exoskeletal structures are present on the exposed parts of the hindlimbs. These scales originate from the epidermal part of the skin and remain arranged in tile-like fashion. (*iv*) **Feathers.** These exoskeletal structures are the unique features of birds and are not seen in any other animals. The feathers constitute the principal body covering of pigeon and are supposed to be modified reptilian scales. They cover the most parts of the body and form the wings and tail. Each feather originates from the epidermal layer of the skin and are arranged in definite tracts called *pterylae*, which are separated from the featherless tracts called *apteria* (Fig. 8.3). The arrangement of feathers on the body of pigeon is called the *pterylosis*. Feathers may be white (due to the presence of air space) or coloured (due to the presence of pigments). The colour of the feathers is due to chemical pigments and the physical arrangement of the elements composing the feathers. Feathers are periodically replaced by a process called moulting, which occurs sporadically throughout the body. The feathers of pigeon may be classified into two groups: (A) FLIGHT FEATHERS. These feathers are associated with flight and may again be subdivided into *wing feathers* or *remiges* and *tail feathers* or *rectrices*. The remiges are present in the wings and each wing has 23 feathers, which are again subdivided into *primaries*, *secondaries* and *tertiaries*. The remiges attached to the distal part (carpometacarpus) of the wing are primaries, those on the middle (radius and ulna) portion are secondaries and those

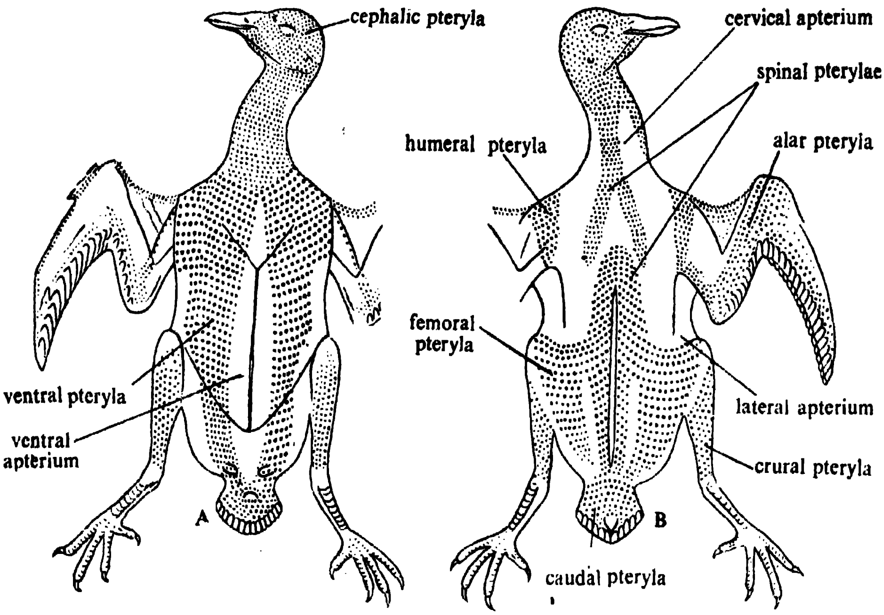


Fig. 8.3. Feather tracts of *Columba*. A. Ventral view. B. Dorsal view.

attached to the proximal part (humerus) of the wing are called the tertiaries. The rectrices are twelve in number and are arranged semi-circularly in the tail region. (B) COVERING FEATHERS. These are responsible for the general covering of the body and are of three types: *Contour feathers*, *Filoplumes* or *hair feathers* and *Down feathers* or *plumules*. The contour feathers form the majority of the covering feathers and filoplumes remain in between the contour feathers. The down feathers are also present in between the contour feathers. In the body of the nestling it is called powdered down feather.

The feathers differ in their size, shape and function, but are built up in same general plan. A typical feather has the following three parts—*shaft*, *vane* or *vexillum* and *aftershaft* (Fig. 8.4). The shaft portion is divisible into two parts, *calamus* and *rachis*. The calamus is the hollow cylindrical stalk by which the feather remains attached with the skin. At the proximal end, there is an aperture called *inferior umbilicus* into which fits the mesodermal papilla of the skin. At the distal end, there is another aperture called *superior umbilicus*. The rachis is solid pith-like in appearance and is continuous with the calamus. The vane or vexillum represents the broad part of the feather. It is formed by delicate closely set structures, called *barbules* or *rami*, which extend from each side of the rachis. The distal edge of each barb has two sets of *barbules*—proximal and distal. The proximal barbule from one barb crosses the distal barbule of the next. The tips of the distal barbules are provided with hooklets and the tips of proximal barbules have flanges. The hooklets and flanges interlock to render a compact surface of the vane which resists the air. The aftershafts are few hairy processes present just proximal to the superior umbilicus.

In the flight feather, the shaft is long and vanes are broad. Among the covering feathers, the contour feathers have short shaft but extended vane portion. Each filoplume has a long shaft carrying a few degenerated barbs and barbules at the tip and such barbs are without interlocking apparatus. Similarly the down feathers are also without interlocking apparatus in the barbs. The down feathers consist of a short quill or stem. The barbs are arranged in a circle at the top of the stem. The barbs have minute barbules.

Each feather is provided with a muscle at its base, which controls the position of feather. The nerve fibres present at the base also help the feather to act as a sensory structure. The feathers produce a compact surface to resist air-current. In addition, it retains heat and thus helps the bird from the temperature hazards. It is light and therefore helps in flight. In some birds, a few feathers act as secondary sexual characters.

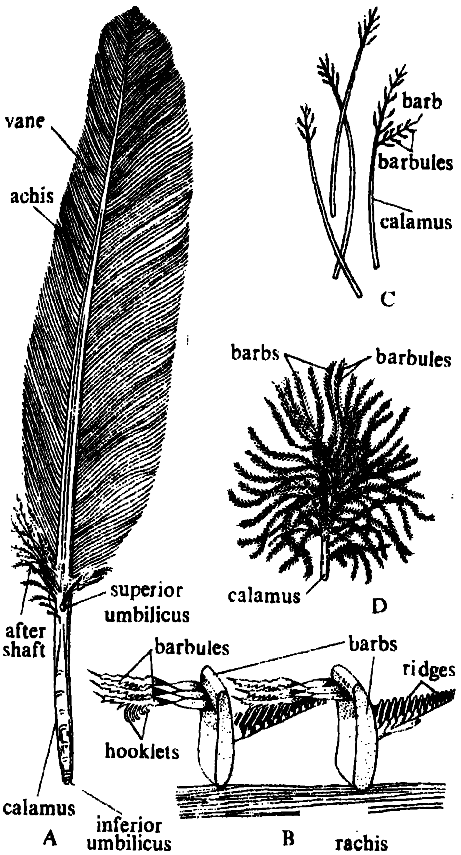

vane
achis
after shaft
calamus
A
superior umbilicus
inferior umbilicus
barb
barbules
calamus
C
barbs
barbules
calamus
D
barbules
barbs
ridges
hooklets
B
rachis

Fig. 8.4. Feathers of *Columba*. A. Typical flight feather. B. Sectional view of two barbs showing the disposition of the barbules and the locking mechanism. C. Filoplume. D. Down feather.

Development of feathers. The germ of a developing feather begins as a papilla of the skin composed of epidermis and dermis. (Fig. 8.5 A, B). At the initial stages, the dermal cells push the overlying epidermis up ahead of it. The base of the outgrowth gradually sinks into the skin. This outgrowth includes dermis and epidermis. The epidermis becomes hard and cornified and is pushed out from the papilla region. The dermal plug gradually withdraws leaving a hollow quill inserted is the skin. The embryonic feather is, thus a tube of cornified epidermis set in a pit of dermis. One side of tubular embryonic feather becomes considerably thickened to transform into the shaft (Fig. 8.5C). From the shaft slanting barbs are developed on either side. The wall of the tube opposite the shaft becomes very thin. Rapture of this thin portion causes the spreading out of the rolled-up feather to assume its usual form.

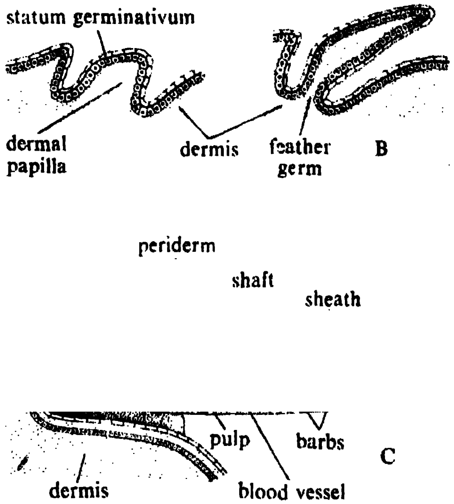

statum germinativum
dermal papilla
dermis
feather germ
B
periderm
shaft
sheath
pulp
barbs
C
dermis
blood vessel

Fig. 8.5. Development of a contour feather of *Columba*. A, B. Sectional views of early stages. C. Stereogram of late stage of development.

Endoskeleton

Pigeon possesses well-developed endoskeleton. The entire endoskeletal frame may be grouped into *Axial* and *Appendicular skeletons*. Both these groups have undergone considerable modifications, specially fusion of different parts, to meet the requirements of the bird's peculiar way of life.

Axial skeleton

The axial skeleton includes the *skull*, *vertebral column* and *sternum*.

The skull of pigeon is light and fragile. It is more or less round in shape. The skull bones are paper-like thin. The sutures of the skull bones are obliterated. The opening of the cranium, i.e., *foramen magnum* is directed ventrally and the skull articulates with the vertebral column by a single round *occipital condyle* on the anterior border of the foramen magnum. The cranial part of the skull is formed dorsally by a pair of *parietals* and a pair of *frontals* (Fig. 8.6A). The ventral side of the cranium is formed posteriorly by *basioccipital* and anteriorly by *basisphenoid*. The basisphenoid is drawn anteriorly as a narrow *rostrum*. Ventrally, the basisphenoid gives rise to two membranous *basitemporals* which fuse to form the posterior part of the *presphenoid*. The anterior part of the presphenoid is represented by the rostrum. *Supraoccipital* and the *exoccipital* form the posterior and lateral sides of the cranium (Fig. 8.6B). On each side of the cranium lies the tympanic cavity. It is formed by the *squamosal*, *prootic* and *epiotic* bones. Two orbits are separated by interorbital septum, which is formed by the union of presphenoid and mesethmoid bones. *Nasals* are forked in appearance and form the inner and outer margin of the nasal cavity. A large *lacrymal bone* is present on each side between the orbit and the facial part of the skull. The *facial part* of the skull is united with the cranial part in the following way: Maxilla unites with the *jugal* and *quadratojugal* and ultimately with the *quadrate*. Quadrate is a three-rayed bone which articulates with the tympanic cavity by two processes and sends an orbital process. It bears condyle for the articulation

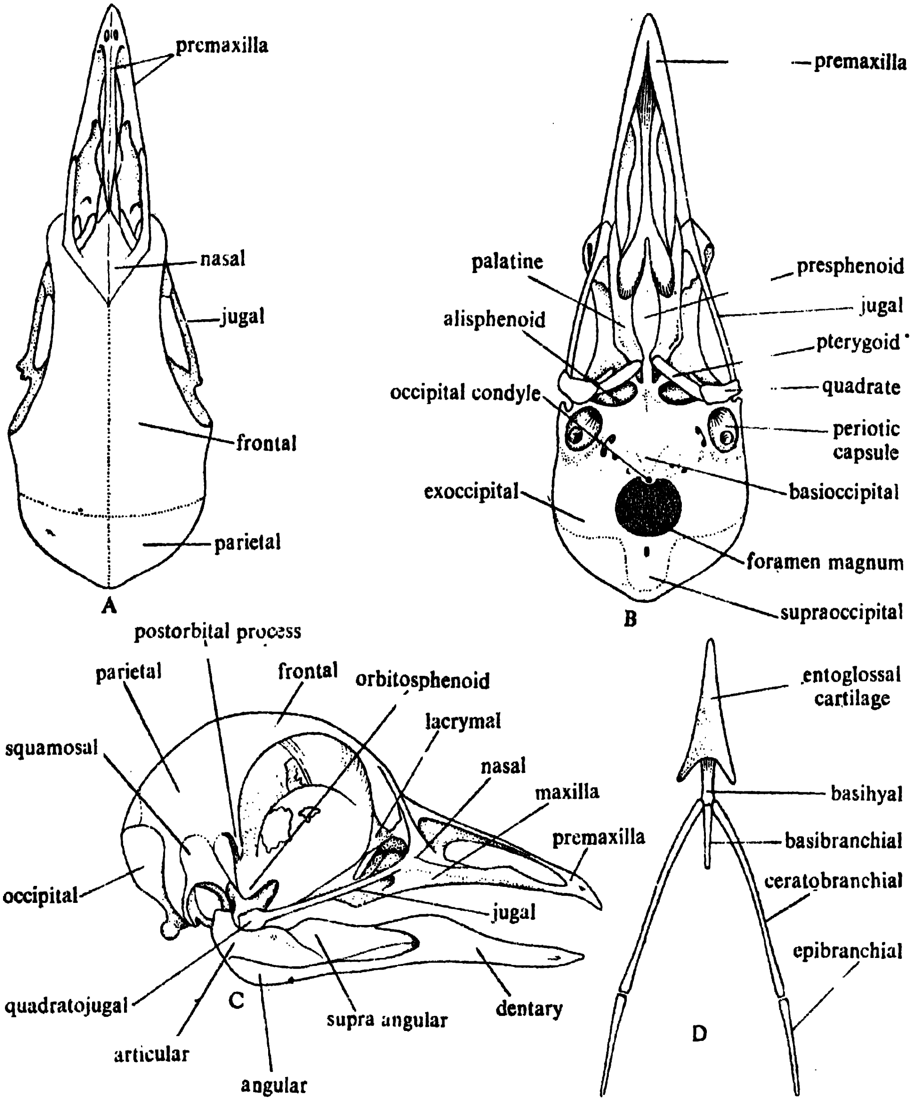

premaxilla
nasal
jugal
frontal
parietal
A
premaxilla
palatine
presphenoid
alisphenoid
jugal
pterygoid
occipital condyle
quadrate
periotic capsule
exoccipital
basioccipital
foramen magnum
supraoccipital
B
postorbital process
parietal
frontal
orbitosphenoid
lacrymal
squamosal
nasal
maxilla
premaxilla
occipital
jugal
quadratojugal
C
supra angular
dentary
articular
angular
entoglossal cartilage
basihyal
basibranchial
ceratobranchial
epibranchial
D

Fig. 8.6. Endoskeletal structures of *Columba*. A. Dorsal view, B. Ventral view and C. Lateral view of skull. D. Hyoid apparatus.

of the mandible. *Palatine* articulates with the *pterygoids* and rostrum posteriorly. The pterygoids articulate with the quadrate and also with the basipterygoid process of the rostrum. The *vomer* is absent in pigeon. The maxillo-palatines remain separate and do not unite medially. This particular type of the skull is called the Schizognathous type of skull. The mandible consists of dentary, supra angular, angular, splenial and articular (Fig. 8.6C).

The hyoid apparatus (Fig. 8.6D) consists of an arrow-shaped *basihyal* from which two short *cornua* originate. It is continued as slender *basibranchial* from which originates a pair of posterior cornua. Each cornu contains *ceratobranchial* and *epibranchial* segments. Dorsally the hyoid apparatus is represented by a slender bone called *columella* which remains united with the stapes of the middle ear by one end and the other end has three cartilages, extrastapedial, infrastapedial and suprastapedial, to fit into the tympanic membrane.

The vertebral column is an elongated structure. It shows flexibility at the anterior part, compactness at the trunk region and shortening near the tail region. Entire column is divisible into three regions, *cervical, thoracic* and *synsacral*. Each region includes several vertebrae.

(*a*) *Cervical vertebrae*. Altogether 14 cervical vertebrae support the neck region of pigeon and are constructed in such a way that while supporting the head they permit free movement of the neck. A typical cervical vertebra (Fig. 8.7 B, C, D) has the following features: (*i*) *Centrum* is *heterocoelous* (anteriorly concave from side to side but convex from above downwards and posteriorly concave from above downwards but convex from side to side). The heterocoelous centra of the neck vertebrae give greater mobility of neck and allow the head to move to an angle of 180°. (*ii*) *Articulating surface* of the centrum contains synovial capsules, cartilaginous plates, meniscus and suspensory ligament. (*iii*) Double headed vestigial *ribs* are directed posteriorly. (*iv*) The *transverse processes* are perforated to allow the passage of vertebral artery, this passage is called the *vertebrarterial* or *transverse foramen*. The first two cervical vertebrae differ from a typical cervical vertebra in structure. In both, the different parts are much reduced. The first vertebra, which is also known as *atlas* is small ring-like and fused with the second vertebra called *axis*. (Fig. 8.7 A, B). (*b*) *Thoracic vertebrae*. Four to five in number, of which the last one is free and the rest are united. The last thoracic vertebra is fused with the synsacrum. In each thoracic vertebra, the centrum is ventrally compressed into a plate, called *hypophysis* (Fig. 8.7E). A pair of ribs remain attached with the

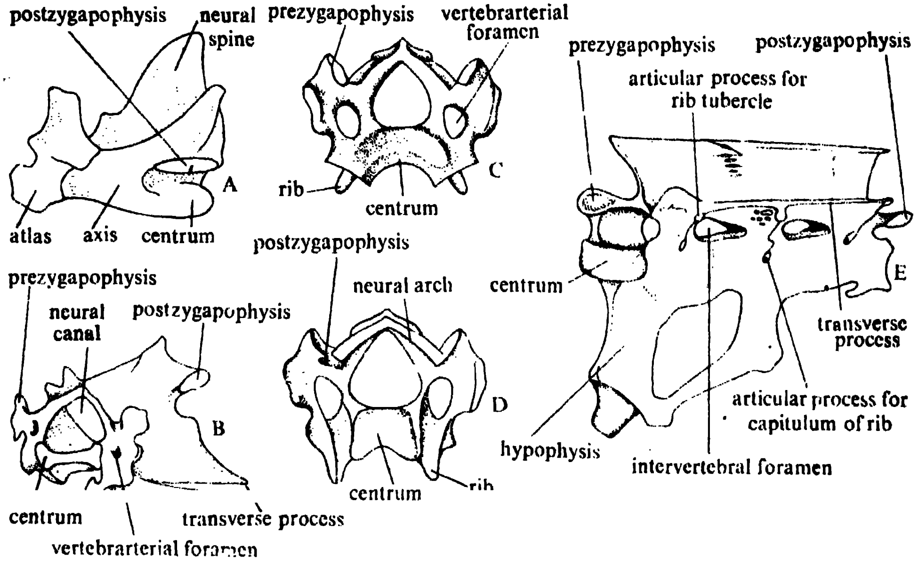

postzygapophysis
neural spine
prezygapophysis
vertebrarterial foramen
A
atlas
axis
centrum
rib
centrum
C
postzygapophysis
prezygapophysis
neural canal
postzygapophysis
B
centrum
transverse process
vertebrarterial foramen
neural arch
D
centrum
rib
prezygapophysis
postzygapophysis
articular process for rib tubercle
centrum
E
transverse process
articular process for capitulum of rib
hypophysis
intervertebral foramen

Fig. 8.7. Endoskeletal structures of *Columba* (Contd.). A. First and second vertebrae. Side view (B), anterior view (C) and posterior view (D) of a cervical vertebra. E. Side view of a thoracic vertebra.

vertebra by two heads—one head is united with the centrum and the other head remains united with the transverse process. This vertebral portion of the rib is attached with a bony counterpart from the sternum and bony interconnections, called the *uncinate processes*, unite these vertebral parts. (*c*) *Synsacrum*. It is a compact more or less triangular skeletal mass formed by the fusion of vertebrae (Fig. 8.8B). Together with pelvic girdle, it renders rigidity to the body. Following vertebrae constitute the synsacrum: (*i*) Posterior thoracic—only one with ribs not connected with the sternum. (*ii*) Lumbar—Five to six in number. Ribs are absent. Transverse processes are placed high on the neural arch and their uniting ligament is ossified to form a dorsal continuous bone. (*iii*) Sacral—Two in number. Transverse processes of each sacral originate near the neural arch and the centrum is provided with a ventral

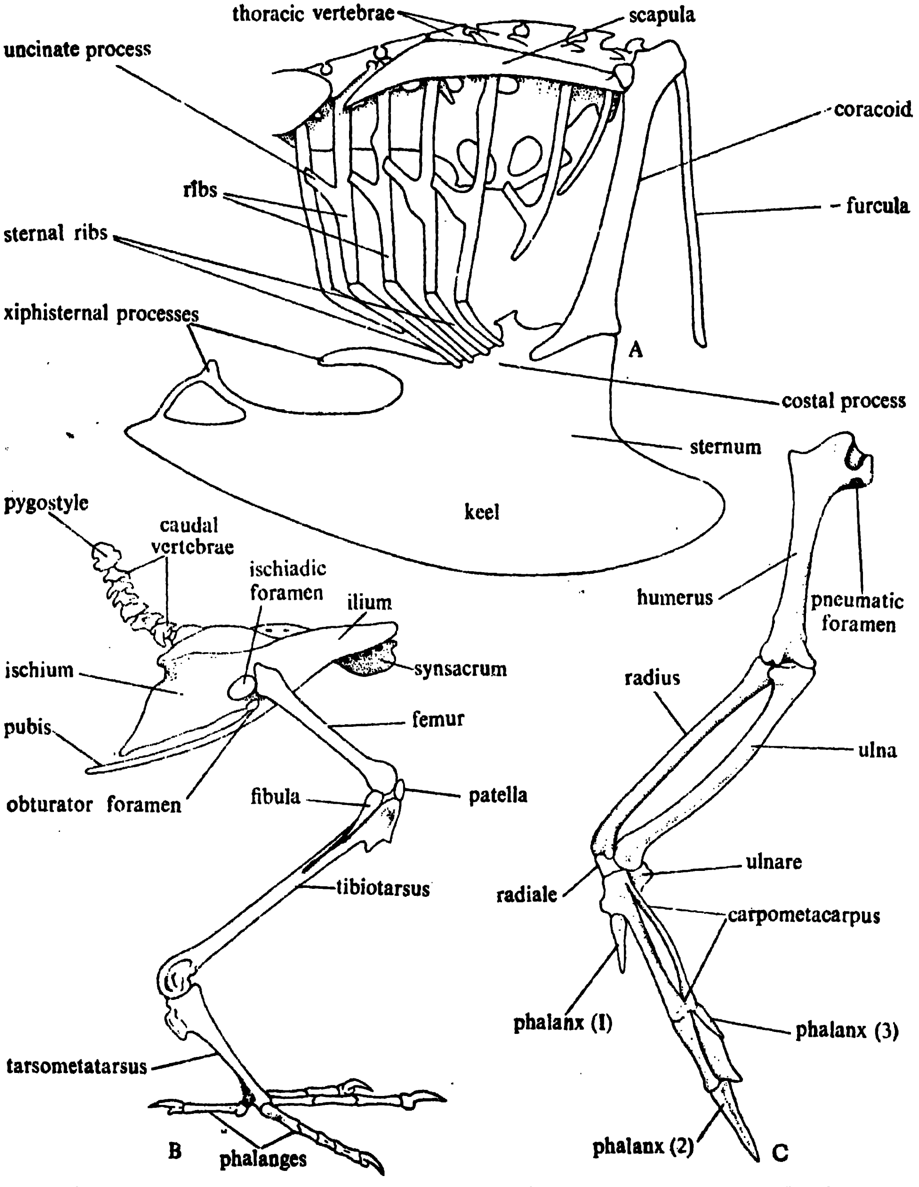

thoracic vertebrae
scapula
uncinate process
coracoid
ribs
furcula
sternal ribs
xiphisternal processes
A
costal process
sternum
pygostyle
caudal vertebrae
keel
ischiadic foramen
ilium
humerus
pneumatic foramen
ischium
synsacrum
radius
pubis
femur
ulna
obturator foramen
fibula
patella
ulnare
tibiotarsus
radiale
carpometacarpus
phalanx (I)
phalanx (3)
tarsometatarsus
B
phalanges
phalanx (2)
C

Fig. 8.8. Endoskeletal structures of *Columba* (Contd.). A. Lateral view of sternum, ribs and pectoral girdle. B Side view of pelvic girdle, tail and hindlimb. C. Side view of forelimb.

outgrowth which lies pressed against the pelvic girdle. (*iv*) Anterior caudal—Five in number and all are fused with the other parts of the sacrum. (*d*) *Posterior caudals*—Six in number. Each one is free and distinct. Each vertebra is with a short and prominent centrum. (*e*) *Pygostyle* or *Plough-share bone*—It is formed by the fusion of last four vertebrae. The pygostyle is a compressed skeletal structure and is turned upwards.

The *sternum* is extremely modified due to the flying habit. It is modified ventrally into a boat-shaped bony skeletal structure called *keel* or *carina*. The anterior part is provided with a pair of grooves for the attachment of the coracoid bones of the pectoral girdle. The posterior part possesses two pairs of notches.

Appendicular skeleton

It consists of skeletal elements which constitute limbs and girdles. Among the limbs, the forelimbs are modified as *wings* and the hindlimbs are modified as *legs*. The bony components of the forelimbs become greatly altered due to the transformation into wings. The skeleton of the hindlimbs have retained the typical reptilian plan. The other skeletal parts are also modified accordingly. The pectoral girdle is built up for the attachment of wings and the pelvic girdle holds the hindlimbs to support the body during standing.

Pectoral girdle and wing. The appearance of the pectoral girdle is altogether different from that of other vertebrates. The pectoral girdle of each side contains following parts: (*i*) *Coracoid*. It is massive, rod-like strongly built bone. Each coracoid is placed on the dorsoventral axis and attached to the broad end with the keel. Anterior end contains a process called acrocoracoid process. (*ii*) *Scapula*. It is a sword-shaped bone which extends anterioposteriorly over the ribs (Fig. 8.8A). At its anterior end, it is connected with the coracoid by a ligament. The coracoscapular angle is less than 90°. This is a characteristic feature of the flying birds. (*iii*) *Furcula* or *wish bone* or *Merry thought bone*. It represents the clavicles and interclavicles of pectoral girdle in other animals. It forms a 'V'-shaped structure and hangs along the dorsoventral axis in front of the sternum. A small aperture (*foramen triosseum*) is left at the junction of the coracoid, scapula and furcula. Through this aperture, the tendon from the wing muscles passes for the attachment with the humerus. (*iv*) *Glenoid cavity*. It is the place where the head of the forelimb fits in. It is formed by both coracoid and scapula, the latter forms acromion process within it. Each wing contains following skeletal pieces: (*i*) *Humerus*. It is a strongly built bone with broad head. The head bears a number of prominent ridges and a *pneumatic foramen*. (*ii*) *Radius* and *Ulna*. Both are separated in the middle but remain closely approxed at the two ends. Radius is a slender, straight skeletal piece, while ulna is curved and slightly bent. (*iii*) *Proximal carpals*. Two large skeletal pieces, one called the *radiale* and the other called the *ulnare* remain free. (*iv*) *Carpometacarpus*. This small but compact bone includes two skeletal pieces, which are fused at both the ends but separated in the middle. One piece is stout and straight, while the other piece is slender and curved. It is formed by the union of two distal carpals and three metacarpals. (*v*) *Phalanges*. Following phalanges are present in each limb, all of which are devoid of claws. They are: (*i*) One pointed phalanx is attached with the first metacarpal. (*ii*) Two phalanges remain attached with the second metacarpal, one of them is flange-like and the other one is pointed. (*iii*) One pointed phalanx is attached with the third metacarpal (Fig. 8.8C).

Pelvic girdle and *hindlimb*. The pelvic girdle is compact and ankylosed with the synsacrum. It contains following skeletal parts in each side: (*i*) *Ilium*. It is a broad and large bone, fused with the synsacrum on its inner side. It is concave anteriorly and convex posteriorly. (*ii*) *Ischium*. It is a broad bone, which is fused with the ilium at its posterior end. Anteriorly, an ischiatic foramen separates the ilium from ischium. No ischiatic symphysis is present. (*iii*) *Pubis*. It is a narrow curved elongated skeletal piece, which is placed parallel to the ischium and separated from it by *obturator foramen*. No pubic symphysis occurs in pigeon. (*iv*) *Acetabulum*. It is the cavity where the head of the femur fits in. Its dorsal side is formed by the ilium and the remaining part is formed by the equal share of ischium and pubis. The edge of the cavity is drawn into a process called antitrochanter, which works against the trochanter of the femur of hindlimb (Fig. 8.8B).

Each hindlimb is composed of following skeletal pieces: (*i*) *Femur*. It is a short and narrow skeletal piece. Its proximal end contains pointed trochanter and rounded head. The hindlimb is placed parallel to the sagittal plane of the body. The distal end is drawn into a pulley like condyles, containing a *patella* as knee-joint. (*ii*) *Tibiotarsus*. It is a long bone formed of tibia with the fusion of two distal tarsals. (*iii*) *Fibula*. It is a small rudimentary bone situated on the lateral surface of the tibiotarsus. (*iv*) *Tarsometatarsus*. This bony segment is formed of some of the tarsals and the metatarsals of the second, third and fourth digits. A small vestige of the first metatarsus is located on the posterior side of the distal end of the tarsometatarsus. The ankle joint of bird being mesotarsal resembles that of reptile. (*v*) *Phalanges*. Pigeon has four digits; the fifth one is lacking. Phalanges are present in the following number at different toes and the distal phalanges of all the toes are provided with sharp and pointed claws. The first toe or *hallux* has two phalanges and the second, third and fourth toes have three, four and five phalanges respectively.

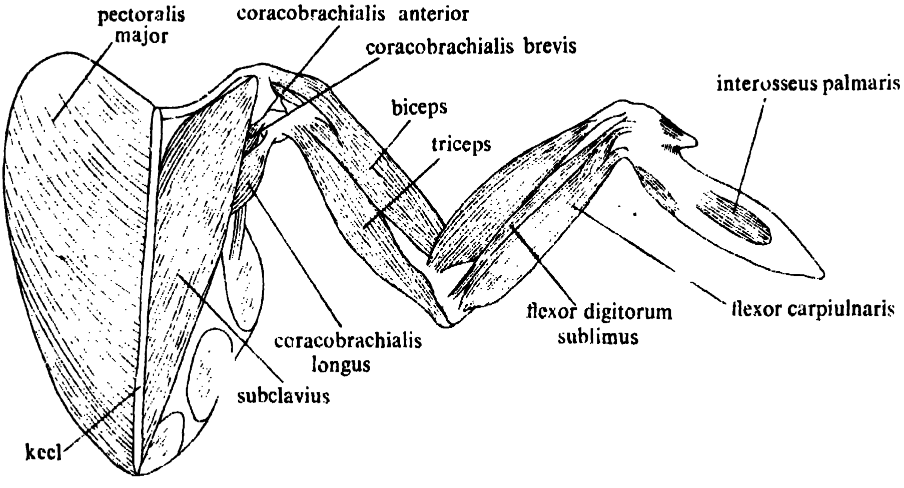


Fig. 8.9. Ventral of breast and wing musculature of *Columba*.

MUSCULAR-SYSTEM

The muscular system of pigeon is extremely modified to meet the requirements of its peculiar way of life. The muscles of the active regions, i.e., breast and wings, legs, neck, tail are highly developed, whereas in the comparatively immobile regions, partly the back muscles become atrophied. Some muscles in pigeon's body have changed their function due to the modifications for flight. The myofibrils composing the muscles are extremely elongated and they can withstand fatigueness during prolonged activity. There are many muscles in pigeon, of which, the following muscles connected with the activities of the wings and legs are described below.

Breast and wings muscles. The muscles which are concerned with the activity of the wings are called flight muscles (Fig. 8.9). Flight in pigeon is caused by the action of the following muscles:

(1) **Pectoralis major.** These are paired muscles of immense size. These are highly vascularised and constitute about one-fifth of the total weight of the body. Each muscle arises from the whole of keel of sternum and from the clavicle. It is present over the entire area of the breast bone and its fibres are inserted into the great trochanter of humerus. They constitute the main depressor muscles of the wings and the powerful downstroke is caused by these muscles.

(2) **Pectoralis minor** (or **Subclavius** or **Supracoracoideus**). These paired muscles are situated on the dorsal side of the pectoralis major and on the anterior side of the sternum proper rather than the keel. Each muscle sends its tendon through the *foramen triosseum* (aperture between furcula,

scapula and coracoid) and inserts itself into the anterodorsal surface of humerus. The foramen acts as a pulley. These are the main elevator muscles of the wings.

(3) **Scapulo-humeralis** (**Posterior** and **anterior**). These small muscles are stretched from the pectoral girdle to humerus and are responsible for the rotatory motion of the wing in the glenoid cavity.

(4) **Tensor patagialis longus.** It originates from pectoralis major and remains inserted into the patagial membrane. It acts as a tensor of patagial membrane.

(5) **Rhomboideus externus.** It originates from the spines of all thoracic vertebrae and last few cervical vertebrae. It is attached with the ventral border of scapula and draws the scapula medially.

(6) **Rhomboideus profundus.** It originates from all thoracic vertebrae and is inerted into the vertebral border of scapula beneath the rhomboideus externus. It also draws the scapula medially.

(7) **Scapulo-humeralis anterior.** This muscle arises from the anterior axillary border and head of scapula. It is attached with the humerus just proximal to pneumatic foramen and draws the humerus medially.

(8) **Scapulo-humeralis posterior.** It originates from the entire lateral surface of the scapula and remains inserted into the humerus, distal to pneumatic foramen. It also draws the humerus medially.

(9) **Latissimus dorsi.** It arises from the spines of thoracic vertebrae and remains attached on the humerus between attachment of triceps and deltoideus major. It draws the humerus medially.

(10) **Serratus anterior.** This muscle originates from the fascia covering third rib ventral to uncinate process. It is inserted into the ventral border of scapula anterior to the origin of scapulo-humeralis anterior muscle. It depresses the scapula.

(11) **Serratus posterior.** It arises from the fascia covering fourth, fifth and sixth ribs near the level of uncinate process. It is connected with the medial border of the posterior one-third of the scapula. It also depresses the scapula.

(12) **Tensor patagialis brevis.** Arising from the dorsal surface of scapula superficial to deltoideus major, this muscle is inerted into the tendonous to the lateral surface of the elbow to elevate the humerus.

(13) **Scapulo-humeralis profundus.** It takes the origin from the neck of scapula and is attached to the anterior distal one-half of humerus. It draws the humerus medially and posteriorly.

(14) **Tensor accessorius patagialis.** It originates from the fascia covering the biceps muscle and remains inserted into the patagial membrane and keeps the patagial membrane tensely stretched when the wing is extended.

(15) **Expansor secundariorum.** This is a smooth muscle and originates from the long tendon from scapula and fascia of scapulo-humeralis posterior muscle and distal end of the humerus. It is connected with the bases of the proximal five secondary remiges and ventral coverts. It helps the expansion of the remiges.

(16) **Deltoideus major.** It elevates the humerus and arises from the dorso-anterior border of scapula to insert into the great trochanter of humerus.

(17) **Coracobrachialis anterior.** It originates from the distal end of the procoracoid and attaches itself with the great trochanter of humerus to assist the action of deltoideus muscle.

(18) **Coracobrachialis longus.** This muscle draws the humerus medially and also depresses the wings. It arises from the coracoid and remains attached with the humerus, proximal to pneumatic foramen.

(19) **Coracobrachialis brevis.** It also arises from the coracoid and inserted into the humerus to assist the action of coracobrachialis longus.

(20) **Triceps.** It is a large fleshy muscle and originates by two heads from the humerus. It is connected with the tendon of *anconeus muscle* to the olecranon process of ulna. It acts to extend the antibrachium.

(21) **Biceps.** It acts as the flexor of the antibrachium. Its long head arises from scapuloclavicular joint, while the short head originates from the head of the humerus. It is inserted into the anteroproximal surface of radius.

(22) **Brachialis inferior.** This muscle arises from the distal end of humerus and attaches itself with the proximal ventral surface of ulna. It assists the activity of biceps muscle.

(23) **Pronator sublimus.** It helps the pronation of wing. It arises from the distal end of humerus and is attached to the anterodistal surface of radius.

(24) **Pronator profundus.** It also assists the pronation of wing. It arises from the proximal one-third of ulna and attaches itself with the distal end of radius.

(25) **Ectepicondylo-radialis.** It helps the activity of biceps. Originating from the lateral epicondyle of humerus, it is inserted to the shaft of radius.

(26) **Anconeus.** It assists the activity of triceps. It also arises from the lateral epicondyle of humerus and is attached with the lateral surface of ulna.

(27) **Extensor digitorum communis.** Arising from the distal end of humerus, it is attached with the posterodistal surface of carpometacarpus and pollex. It flexes the pollex, extends the index digit, elevates and flexes the hand.

(28) **Flexor metacarpi radialis.** It flexes the hand. This muscle originates from the fascia of anconeus muscle and is inserted into the outer surface of carpometacarpals.

(29) **Flexor digitorum sublimus.** It also flexes the hand. It originates from the distal end of humerus and remains attached with the proximal and distal anterior surface of carpometacarpus.

(30) **Flexor digitorum profundus.** It arises from the proximal one-third of ulna and attaches itself to the anterodistal border of carpometacarpus by an elongated tendon. It flexes the hand.

(31) **Flexor carpiulnaris.** Originating from the distal end of humerus, it attaches to the posterior proximal surface of carpometacarpus to flex the hand.

(32) **Abductor pollicis.** It abducts the pollex. This small muscle arises from the anterior surface of carpometacarpus distal to pollex and inserted to the ventral surface of pollex.

(33) **Adductor pollicis.** This muscle adducts the pollex. It originates from the anterior surface of carpometacarpus proximal to pollex and attaches to the posterior surface of pollex.

(34). **Extensor metacarpi radialis.** This muscle extends the wing. It originates from the lower end of humerus and remains inserted into the carpometacarpus, proximal to first digit.

(35) **Ulni-metacarpalis ventralis.** It arises from the middle third of ulna and attaches to the carpometacarpus proximal to pollex by a strong tendon. It acts as pronator.

(36) **Ulni-metacarpalis dorsalis.** It elevates and flexes the hand. It arises from the distal end of ulna and inserted to the proximal carpometacarpus.

(37) **Interosseus palmaris.** It elevates the index digit. After originating from the ventral surface of carpometacarpus it is connected with second and third digits.

(38) **Interosseus dorsalis.** It arises from the dorsal surface of carpometacarpus and is inserted to the second and third digits. It also elevates the index digit.

(39) **Extensor pollicis longus.** This muscle extends the hand and arises from the distal half of radius to insert into the carpometacarpus proximal to the first digit.

(40) **Deltoideus minor.** It originates from the head of scapula and attaches to the great trochanter of humerus. It elevates the humerus.

Leg muscles. The leg masculature of pigeon is highly specialised and assists to perch on the branches of the tree, besides walking on land. The muscles are:

(1) **Peroneus longus.** It originates from tibia and remains inserted to the tendon of flexor perforans et perforatus digiti (III). It flexes the digits.

(2) **Peroneus brevis.** This muscle assists in extension and abduction of tarsometatarsus. It arises from the posterior proximal portion of tibia and united with the lateral surface of ankle.

(3) **Gastrocnemius.** It arises from three heads: (*i*) lateral condyle of femur, (*ii*) medial surface of head and neck of tibia and (*iii*) ilium near the *femurocaudalis* muscle. It joins with the tarsometatarsus and phalanges and assists in the extension of tarsometatarsus.

(4) **Plantaris.** After originating from the medioproximal shaft of tibia, it is attached with the *tibial cartilage* (heel) to help extension of tarsometatarsus.

(5) **Tibialis anticus.** It has its start from the external condyle of femur and anterior surface of the head of tibia and joins with the metatarsus. It flexes the tarsometatarsus against shank.

(6) **External digitorum longus.** This muscle acts as a common extensor of the digits. It starts from the anterior surface of tibia beneath the peroneus brevis and ends in the distal phalanges of all digits.

(7) **Flexor perforans et perforatus digiti (III).** It acts as the flexor of third digit. It arises from the medial condyle of tibia and remains inserted into the second phalanx of the third digit.

(8) **Flexor hallicus longus** and **Flexor hallicus brevis.** The former one arises from the lateral condyle of femur and the last one originates from the tibia. Both the muscles

join with the ventral surface of first digit and act as the flexors of first digit.

(9) **Flexor perforatus digiti (II).** It originates from the tibia and joins to the median surface of the first phalanx of second digit. It acts as adductor of second digit.

(10) **Flexor perforatus digiti (IV).** It acts as adductor of fourth digit. After arising from the tibia, it is inserted to the median surface of first phalanx of fourth digit.

(11) **Extensor hallicus.** This muscle arises from the metatarsus and attaches itself to the dorsal surface of first digit. It extends the first digit.

(12) **Lumbricalis.** This muscle acts as the flexor of third digit. It arises from the tendons of flexor muscles and is inserted into the third digit.

LOCOMOTION

Like other flying birds, pigeon is specially adapted to move both in the air and on land. Flight is caused by the activity of the wings and other structures also help in the process. In addition to its ability to fly, pigeon can stroll on the ground and at the same time can perch on the branches of the trees.

Flight mechanism of pigeon

The flight involves certain complicated and delicate steps. In order to fly efficiently, the body of pigeon like all others flying birds is built up in a special design. The details of flight mechanism is still incompletely known. However, the following account will give an idea.

Principles of flight

When our hand is stretched out from a running motor car or train, it is felt that the hand (which is slightly convex on the upper surface) is pushed upward and if the air-current is strong it can support the hand in air. This upward pushing is called *lifting*. If the air-current is not strong enough, then the *drag* of the centre of gravity will bring the object downwards. It means that in order to remain suspended in air, there must be enough force to negativate the drag force and that must be proportional to the weight of the individual. The same principle is applicable to the flight of bird. In pigeon, the forelimbs are modified as wings. These wings not only work as the surface where air-current acts to lift, but also is specially built to produce necessary air current required for the lifting of the body. Flight does not mean only the support of the body in air; together with lifting the bird will have to move forward. Both these functions during flight are carried by wings either by *flapping* or *gliding*. Of these two aspects of flight, lifting and moving forward, the bird spends more energy in the former than the latter. The secret of success of flying lies in the special modifications of the body which will be discussed in details in the last portion of this chapter (vide page 314).

Perching mechanism

The hindlimbs of pigeon are typically built on the reptilian plan. Pigeon, like other flying birds, has the ability to perch on the branches of the tree. Some muscles in the legs are modified in such a fashion that the toes can close round the twig automatically when it sits on the tree. There are four digits in the hindlimbs which are flexed by two sets of tendons. The tendon of the hallux arises from the flexor perforans muscle (Fig. 8.10). The tendons of the three forwardly directed digits are formed by the trifurcation of the tendon coming from peroneus muscle. The tendons are so oriented that a pull upon any tendon flexes the toes. When the bird settles on the branch of a tree, the legs are bent and puts the flexor tendons on the stretch. With the exertion of the pull, the toes are bent

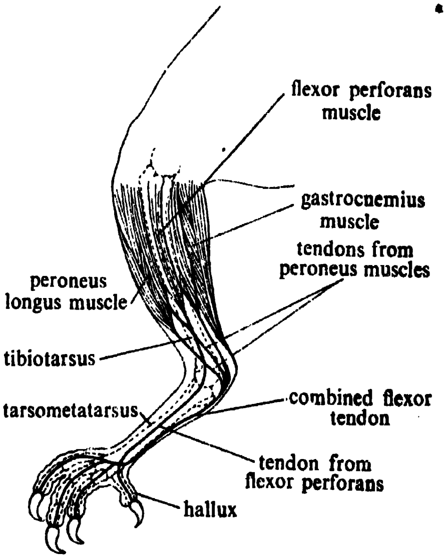


Fig. 8.10. Leg muscles of *Columba*.

spontaneously around the perch. A bird can go to sleep in this position without any fear of falling off. To unlock the feet, it is obligatory for the bird to raise its body to straighten the leg and loosening the tendons which have been pulled tight over the ankle during perching. It is interesting to note that the foot contains no muscle, but the working of the digits is controlled by tendons coming from the muscles situated in the upper sector of the legs. It has been claimed that some other muscles also assist in the process of perching. The role of *ambiens* (a thigh muscle originating from the pubis and travels along the entire length of the leg to join the muscles of the toes) in perching is a disputed issue.

DIGESTIVE SYSTEM

The digestive system of pigeon includes *alimentary canal* and *digestive glands* and provides the nutrition. In comparison to the size of the bird, the length of the alimentary canal is short and its different parts are modified in such way that assimilation occurs in a short time. The digestive system is highly modified in pigeon due to the loss of teeth and also as an adaptation for aerial life.

Structure of the alimentary canal

The alimentary canal consists of the following parts: (*i*) *Mouth*. This inlet aperture is present at the tip of the head and is bounded by horny upper and lower beak. Teeth are totally absent. (*ii*) *Mouth cavity* and *pharynx*. Mouth leads into mouth cavity and pharynx. These regions contain: (*a*) ***Internal nostril***. It is a single opening on the root of the pharynx through which both the nares open internally. (*b*) *Tongue*. It is a prominent structure with free pointed anterior end. Some taste buds and numerous mucous glands are present on the surface. (*c*) *Glottis*. It is an aperture which leads into trachea and is placed near the base of the tongue. (*d*) *Gullet*. It is the last part of the pharynx which continues as an opening into the next part of the alimentary canal. (*iii*) *Oesophagus*. It begins from the gullet and runs through the ventral part of the neck as a straight tube. Near the junction of neck and trunk it comes between skin and muscle and enlarges to form a sac, called the *crop*. The crop plays dual role in the life of pigeon and other birds. It acts as a large temporary *reservoir* of crude food grains. The presence of crop enables the bird to ingest a considerable quantity of food grains very quickly. Besides its normal function of storage, the epithelial lining of the crop produces a proteinaceous, white slimy secretion called the '*pigeon's milk*'. This is produced in both the sexes during breeding season. The young squabs are fed by the parents by regurgitation of the fluid. The secretory activity is controlled by the prolactin hormone of anterior pituitary. The composition of pigeon's milk is given below:

Water	..	65–81%
Protein	..	13.3–18.8%
Fat	..	6.9–12.7%
Ash	..	1.5%

It has a great nutritive value even more efficient than that of mammalian milk. From the crop, the oesophagus enters within the cavity of the trunk and passes dorsal to the heart to open into the next part called the stomach. (*iv*) *Stomach*. It is divisible into two distinct parts: (*a*) *Proventriculus*. It is the first part of the stomach to receive the oesophagus (Fig. 8.11A). It is tubular and internally lined by numerous gastric glands. A red coloured small *spleen* remains morphologically attached to the outer side of the proventriculus. (*b*) *Gizzard*. It is the second part of the stomach and is semicircular in outline. The walls of the gizzard are highly muscular and contains very little inner space. Internally the wall contains numerous ridges and its epithelial lining becomes very thick and tough. It has innumerable small tubular glands. A few stones which are swallowed by the bird, remain within the lumen and are responsible for crushing the food (Fig. 8.11B). The function of gizzard is purely mechanical and acts mainly as the grinding machine to crush the food. The gizzard compensates the role of teeth in pigeon. In grain eating birds the gizzard is highly muscular, while that of piscivorous birds, it is simple and thin-walled. (*v*) ***Intestine***. Intestine begins from the gizzard near the opening of proventriculus and is divisible into following parts: (*a*) *Duodenum*, (*b*) *Ileum* and (*c*) *Rectum*. *Duodenum*. This is the first part of the intestine and is distinctly 'U'-shaped in appearance. Internally, the duodenum contains *villi*, *crypts of Lieberkuhn* and *goblet cells*. *Ileum*. It is the second part of the intestine having numerous villi inside it. The length of the ileum is shorter than that of other animals. The first and the last parts of the ileum are loop-like and the middle part is spirally coiled. ***Rectum.*** It is the last part of the intestine and is of same thickness as that of ileum. Near the junction of ileum and rectum, originates a pair of small lateral blind leaf-like ***caeca.*** (*vi*) *Cloaca.* Rectum opens into a chamber called cloaca. The cloaca is spacious, muscular and is divisible into three chambers: ***coprodaeum, urodaeum*** and ***proctodaeum*** (Fig. 8.11C). The coprodaeum receives the intestine. The urinogenital ducts open within the urodaeum and the proctodaeum opens externally by the vent. In the nestlings, a special thick walled glandular chamber, ***bursa fabricii***, remains in close association with cloaca and communicates with the proctodaeum. It degenerates in the adult bird. The bursa fabricii may have some local protective function in young ones. (*vii*) ***Cloacal aperture.*** The proctodaeum of cloaca opens to the exterior through the cloacal aperture or vent. It is present on the ventral side and near the base of the tail.

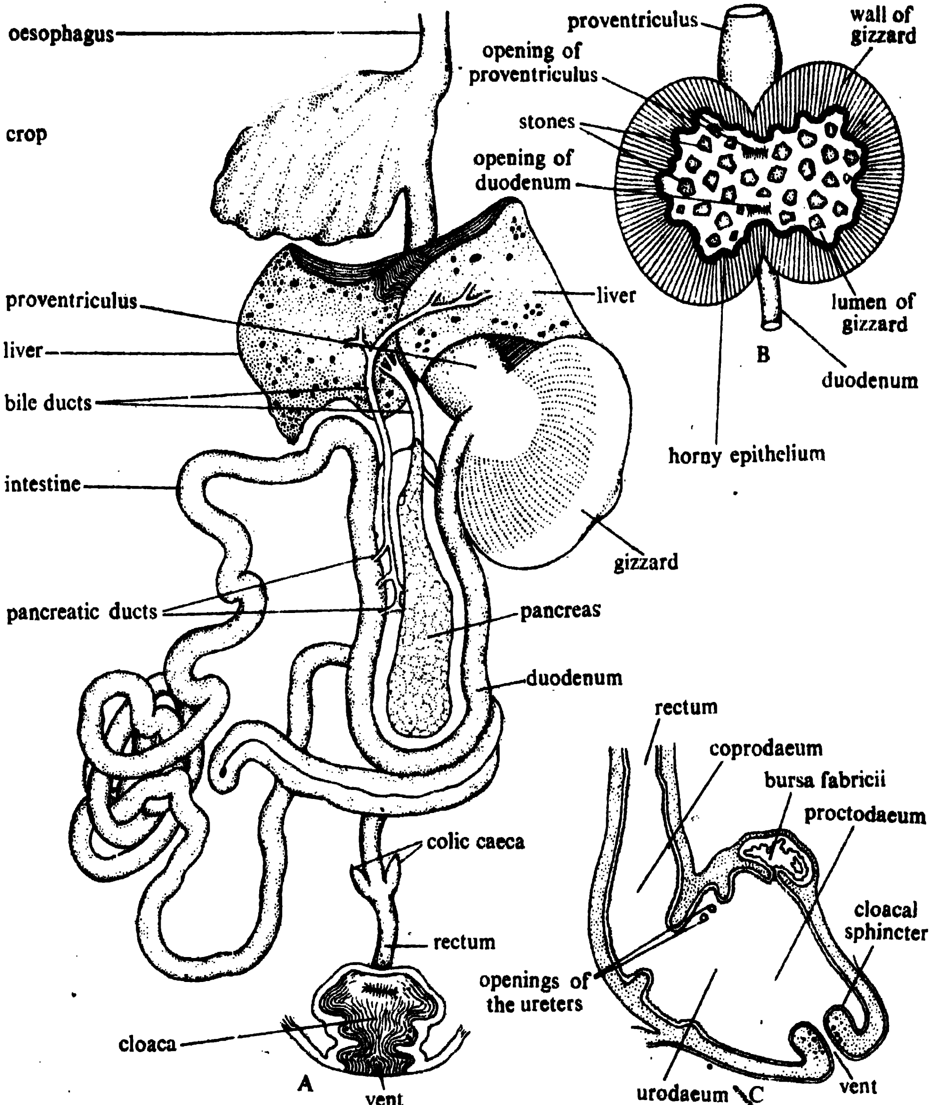

oesophagus
crop
proventriculus
liver
bile ducts
intestine
pancreatic ducts
cloaca
A
vent
proventriculus
opening of proventriculus
stones
opening of duodenum
liver
gizzard
pancreas
duodenum
colic caeca
rectum
wall of gizzard
lumen of gizzard
B
duodenum
horny epithelium
rectum
coprodaeum
bursa fabricii
proctodaeum
cloacal sphincter
openings of the ureters
urodaeum
C
vent

Fig. 8.11. A. Digestive system of *Columba*. The cloaca is longitudinally cut. B. Sagittal sectional of gizzard. C. Longitudinal section of cloaca showing the different regions.

Digestive glands

Following digestive glands are associated with the alimentary system: (1) *Mucous glands*. These are present on the surface of the tongue and crop and are responsible for the moistening of the food. (2) *Salivary glands*. Paired *angular* and unpaired *sub-lingual salivary glands* are located in the pharyngeal region. The secretion called saliva moistens the food and also contains diastatic enzyme. (*iii*) *Crop glands*. The secretion called "crop-milk or pigeon's milk" is produced by these glands. It is used for the nourishment of the young. (*iv*) *Gastric glands*. Present on the internal lining of proventriculus and secretes gastric juice. (*v*) *Tubular glands*. These glands are present on the internal lining of gizzard. The fluid secreted by these glands is thick, horny, yellowish green in colour. (*vi*) *Liver*. Paired deep brown coloured glands of immense size are present ventral to the gizzard. It produces the juice called bile which passes through two bile ducts one coming from each lobe of liver. The bile ducts open separately within the two limbs of the duodenum. The gall bladder is absent in pigeon. (*vii*) *Pancreas*. It is a pinkish white gland located in between the two limbs of the duodenum. It is a combination of both exocrine and endocrine glands. The exocrine part producing pancreatic juice opens into the duodenum by two or three *pancreatic ducts*. The endocrine part produces insulin, which is directly poured in the blood vessel. (*viii*) *Crypts of Lieberkuhn* and *Goblet cells*. These are present in the lining of the duodenum and secrete juice called *secretin* which influences the pancreas to produce pancreatic juice. (*ix*) *Glands in the ileum*. These glands produce digestive juices which contain various enzymes. (*x*) *Caecal glands*. Produce certain digestive juices for the digestion of vegetable fibres. They are also concerned with the absorption of water.

Physiology of digestion

The physiology of digestion in pigeon involves the three following steps:

Ingestion. Pigeon is a grain or seed eater. It picks up grains very rapidly which are quickly swallowed. The shape of the beak is modified in such a way that it helps in its ingestion. The swallowed food being moistened by mucus, is stored in the crop.

Digestion. Within the crop the food is moistened and macerated. The passage of food from crop to proventriculus is regulated. Inside the proventriculus, the gastric juices containing HCl and Pepsin act over the food. Within the gizzard the food is completely churned by the action of gizzard wall and stones. The secretion of gizzard glands helps in the process. The churned food while travelling through the duodenum comes in contact with the bile and pancreatic juice. The bile neutralises the acidity and different enzymes present in the various digestive juices. The completely broken down food is absorbed through the lining of small intestine. Residual part passes into the rectum where water is absorbed and the fibres are broken down by the caecal juice.

Egestion. Residual part called the faeces is temporarily stored in the cloaca where it mixes with the urine and is periodically dropped through cloacal aperture.

RESPIRATORY SYSTEM

The aerial mode of life requires more energy. In order to get this energy, pigeon eats a large quantity of food and to break down the assimilated food at a faster rate, the respiratory system is extensively modified. The lungs are proportionately smaller in size, but the functional efficiency is increased by the development of air-sacs. Thus the respiratory system of pigeon has two unique features: (1) presence of a non-elastic, compact *lungs* and (2) possession of several *air-sacs*.

Following structures are present in the respiratory system of pigeon:

External nares. These are paired openings, present near the base of the upper beak and within the *cere*. *Internal nare*. (Single opening which opens at the roof of pharyngeal region) and both the external nares communicate through this common aperture. *Glottis*. This is a slit-like aperture, which is present on the floor of the mouth cavity and near the base of the tongue. It leads into the next part, trachea. *Trachea*. This elongated tube begins from glottis and runs along the neck region along the ventral side of the oesophagus. The trachea is composed of complete bony *tracheal rings* (Fig. 8.12A). Near its commencement, the trachea is enlarged into a chamber called the *larynx*. This chamber is supported by a cricoid cartilage (which is composed of four pieces) and one pair of arytenoid cartilages. In the birds, the larynx does not function as voice box. *Syrinx*. Near the junction of neck and trunk, the trachea is swollen into a chamber called the *syrinx*. It is formed by the dilation of the last three or four tracheal rings and first bony ring of each bronchus. The mucous membrane of the syrinx constitutes a pad-like thickening and is provided with several muscles and membranes. The syrinx is actually the voice box. The syrinx is the characteristic organ of pigeon and many other flying birds. It has a complicated structural construction. A bar of cartilage called the *pessulus* is present at the junction of two bronchi (Fig. 8.12B). It extends dorsoventrally inside the tympanum and holds a small fold of mucous membrane called the *membrana semilunaris*. The inner membranous lining of the bronchi produces inconspicuous *internal tympaniform membranes*. The sound is produced by the vibration of the membrana semilunaris while the pitch of the sound is controlled by the action of the syringeal masculature. The syringeal masculature includes a pair of *intrinsic syringeal muscles* (arise from the lateral sides of the trachea and are attached with the syrinx) and a pair of *sternotracheal muscles* (originate from the sternum and are inserted into the trachea). The position of syrinx can be changed by the action of these muscles. *Bronchus*. Within the trunk, the trachea bifurcates into right and left *bronchi*. The first ring of each bronchus is complete and bony, while the rest are incomplete mesially. The left and right bronchi are called *primary bronchi* or *mesobronchi*. Each mesobronchus in the beginning, is composed of rings of cartilages, but inside the lung such rings are absent. Each primary bronchus enters the lung through a small space called *vestibulum* and extends up to the posterior extremity of lung. Within the lung, the mesobronchus sends a pair of branches called *secondary bronchi* and each secondary bronchus breaks up into a network of *tertiary* or *parabronchi* and send branches to the *air-sacs*. Each tertiary bronchus again subdivides into numerous finer network of tubules (*air capillaries*), which remain in close contact with the blood capillaries. While running posteriorly, the diameter of mesobronchus gradually decreases and it finally opens into the abdominal air-sac by a opening called ostium.

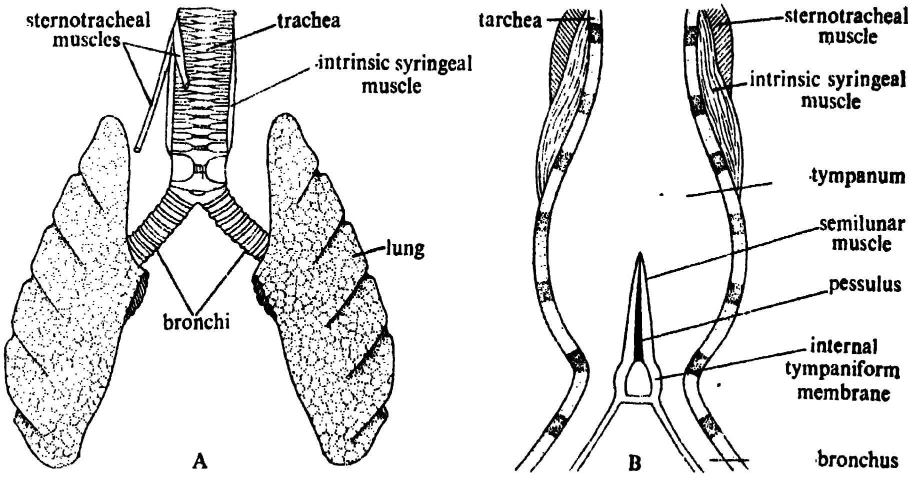


Fig. 8.12. Respiratory organs of *Columba*. A. Trachea, bronchi and lungs. B. Diagrammatic longitudinal sectional view of the syrinx.

Lungs. The lungs are small in size in comparison with that of the body. These are paired pink coloured organs. The wall of each lung is spongy, solid and very little elastic. The dorsal surface of the lungs is fitted closely with the interspaces of ribs and lacks the peritoneal covering. The ventral wall has a compact fibrous tissue sheet called the *pleura* or *pulmonary aponeurosis*. The wall of the pleura has special fan-shaped *costopulmonary muscles* which originate from the joints of vertebral and sternal ribs. The alveolar lining is formed by the ramification of tertiary tubules with the distribution of blood vessels.

Air-sacs. The air-sacs are bladder-like structures. These are formed by the dilation of the mucous membrane of the bronchus. The air-sacs are thin walled membranous sacs and are devoid of blood vessels. Following air-sacs are present in the body of pigeon and all of them remain in communication with the pneumatic cavities of bones. There are nine major and four accessory air-sacs in pigeon (Fig. 8.13).

Major air-sacs. The major air-sacs originate directly from the lungs. Of the nine such air-sacs, four of them are paired and one is unpaired.

(*a*) *Paired air-sacs*

(*i*) Posterior (or abdominal) air-sacs,

(*ii*) Posterior thoracic air-sacs,

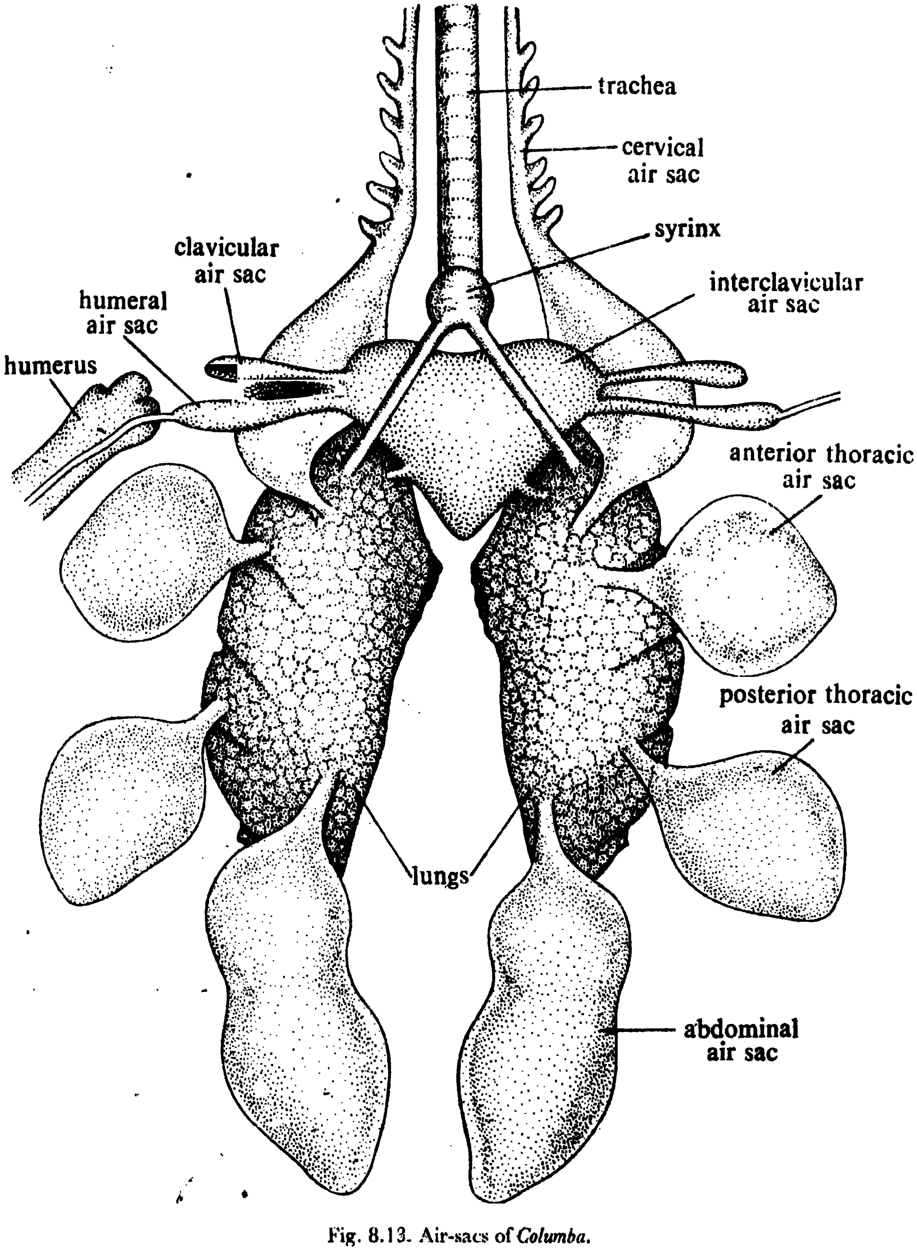

trachea
cervical air sac
syrinx
clavicular air sac
interclavicular air sac
humeral air sac
humerus
anterior thoracic air sac
posterior thoracic air sac
lungs
abdominal air sac

Fig. 8.13. Air-sacs of *Columba*.

(*iii*) Anterior thoracic air-sacs and
(*iv*) Cervical air-sacs.
(*b*) *Unpaired air-sac*
(*i*) Interclavicular or median air-sac.

Accessory air-sacs. These air-sacs originate as paired diverticula from the interclavicular air-sac. These paired sacs are:

(*i*) clavicular air-sacs and
(*ii*) humeral air-sacs.

Abdominal air-sacs. These are also called the posterior air-sacs and lie among the coils of intestine. These are the posteriormost and largest air-sacs in birds. The right air-sac is larger than its left counterpart. These air-sacs send diverticula into the pelvic girdle, synsacrum, hindlimbs and between thigh muscles.

Posterior thoracic air-sacs. These paired air-sacs are placed on the posterior side of the thoracic cavity. The left sac is slightly larger than the right. Both the sacs are closely apposed with the lateral wall of the body cavity. Each bronchus, near its entrance into the lung, gives three short branches: One enters into the anterior thoracic air-sac, the second is connected with the cervical air-sac and the third enters the interclavicular air-sac.

Anterior thoracic air-sacs. These paired air-sacs are located, one on each side of the thoracic cavity towards the anterior part between the lungs and the ribs.

Cervical air-sacs. These paired air-sacs are placed near the base of the neck and in front of the lungs. Each sac sends diverticula into the cervical vertebrae and the skull.

Interclavicular air-sac. This is an unpaired and median air-sac of large size. It has two ducts, one opening into each lung. Although this sac is unpaired in adult, it is formed by the fusion of two sacs which are evident by the presence of two ducts. Each side of this air-sac gives off two extensions — (*i*) Clavicular air-sac and (*ii*) Humeral air-sac. These sacs are communicated with the cavities of the bones.

A layer of fibrous tissue called *oblique septum* encloses the ventral walls of both the thoracic air-sacs. This septum extends up to the pericardium and unites with the similar septum of other side. Such union along the middle line separates the body cavity into two chambers. One chamber houses the lungs, thoracic and interclavicular sacs and the other chamber contains the heart, liver, stomach, intestine and abdominal air-sacs.

Role of air-sacs

The air-sacs play important role in the life of flying birds. The air-sacs are not provided with a capillary network, so they are not directly respiratory in function. Besides, these sacs are essential components for aerial life. The different uses of air-sacs are mentioned below:

Function as bellows. As the lungs are anchored firmly to the dorsal wall of the thoracic cavity, the elasticity of the lungs is greatly hampered. To carry on an efficient circulation of air through the lungs during respiration, some mechanical aid becomes necessary, specially during flight. The air-sacs give the mechanical aid by acting as the bellows.

Act as balloons. When the air-sacs are inflated due to intake of warm air, the specific gravity of the body is lowered to a considerable extent. As the warm air is lighter than ordinary air, the retention of such air inside the air-sacs makes the body considerably lighter. This also lessens muscular efforts to sustain the body heavier than air.

Function as ballast. The air-sacs are so nicely arranged on the two sides of the body, proper centre of gravity is established for balanced flight. If the equilibrium is lost by chance during flight, restoration of the equilibrium is easily maintained by shifting of the contained air from one side of the body to the other.

Lessen mechanical friction. The air-sacs send branches which are inserted between the muscles (specially the flight muscles) like pads. Such a placement of air-sacs reduces mechanical friction to a large extent and increases the flexibility of the wings during flight.

Regulate and maintain body temperature. The skin of bird lacks integumentary glands. So the skin has no utility in the regulation and maintenance of body temperature. Retention of warm moist air inside the air-sacs help to regulate and maintain the body temperature.

Serve as the containers of reserve air. During rest the respiration involves the alternate depression and elevation of the breastbone caused by the activity of the intercostal muscles. But during flight the breastbone as well as the thoracic basket are kept in a rigid state and the intercostal muscles remain in tension. The respiratory process is slightly hampered for the time. Therefore, some internal source of reservoir of air becomes indispensable. The air-sacs subserve this function and ventilate the lungs during flight.

Act as resonator. The pitch of the sound is controlled to some extent by the forceful expulsion of the air from the air-sacs which act as resonator.

Regulate the moisture content of air. Water is evaporated from the walls of the air-sacs in birds. So the air-sacs regulate the water content of the body.

Mechanism of respiration. The unique feature of avian respiration is the double supply of oxygenated air to the surface of lungs for improved aeration. For this reason, the respiration is called double respiration. During *inspiration,* fresh air rushes through trachea and bronchi into the lungs and air-sacs and ultimately diffuses into the air-spaces of the bones. The gaseous exchange takes place only within the lung. At the time of *expiration,* the deoxygenated air from lungs rushes out but the air from air-sacs enter into the lungs. Thus in pigeon, as in all other birds, the lungs are filled up for the second time with fresh tidal air. In other air-breathing animals in between inspiration and expiration, some amount of *residual air* always remains within the cavity of lungs. But in birds the residual air remains inside the air-sacs and to the smaller branches of the bronchi. Because of the fact the aeration of the blood is complete in pigeon and thus increases the respiratory efficiency to yield extra energy.

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The respiratory movements are caused by two sets of muscles, one set operates during flight and the other set works at the time of rest. During flight, both inspiration and expiration are caused by the movements of the pectoral muscles. At the time of rest, inspiration is caused mostly by the activities of *intercostal muscles* and expiration by the movement of abdominal muscles.

CIRCULATORY SYSTEM

Two different fluids circulate through the body of pigeon. The blood, heart and the blood vessels constitute the blood vascular system. Another fluid, the lymph and the lymph channels are included under the lympathetic system.

Blood vascular system

As stated earlier, this system includes the blood, heart and the blood vessels.

Blood. The blood contains plasma and corpuscles. The red blood corpuscles are oval in shape and nucleated. The white blood corpuscles are present in much lesser number but are of different types. The different types of white blood corpuscles are: (*i*) *lymphocytes*, (*ii*) *heterophils*, (*iii*) *polymorpho-nuclear-pseudo-eosinophilic granulocytes*, (*iv*) *basophils*, (*v*) *eosinophils* and (*vi*) *monocytes*. The blood platelets are absent in pigeon, but the blood clots quickly. New blood cells are formed in the bone marrow and the blood corpuscles are destroyed within spleen. The spleen is a red body of oval shape situated on the right side of the proventriculus and attached with it by peritoneum.

Heart. The heart is an oval organ placed in the anterior part of the thoracic cavity but ventral to the oesophagus. The heart is quite large in size in proportion to body size. It is enclosed by a thin white membraneous pericardium and the pericardial cavity contains a serous fluid. The auricles and ventricles are distinctly separated by a groove called the *coronary sulcus*. The *sinus venosus* is absent and is absorbed in the wall of the right auricle. Both *auricle* and *ventricle* are completely divided into right and left chambers (Fig. 8.14). Thus heart is completely four chambered and all the chambers are lined by endocardium. The right auricle is slightly larger than the left auricle. The ventricles are very powerful. The left ventricle contains a round cavity while the right one has a crescentic cavity partly surrounding the left. The auricles and ventricles are divided internally by *interauricular* and *interventricular septa* respectively. The right auriculoventricular valve is flap-like and muscular in nature. The presence of single right auriculoventricular valve is a diagnostic feature of pigeon. The left auriculoventricular valve is membranous and provided with two cusps which are attached with the ridges of the ventricular wall. Cord-like fibres (*chordae tendineae*) are attached to the margins of the auriculoventricular valves and to the walls of ventricles by *papillary muscles*. These muscles control the activity of the auriculoventricular valves via the chordae tendineae. The right auricle receives deoxygenated blood from three caval veins and the left auricle receives oxygenated blood through four pulmonary veins. From the left ventricle originates the single right aortic arch which conveys

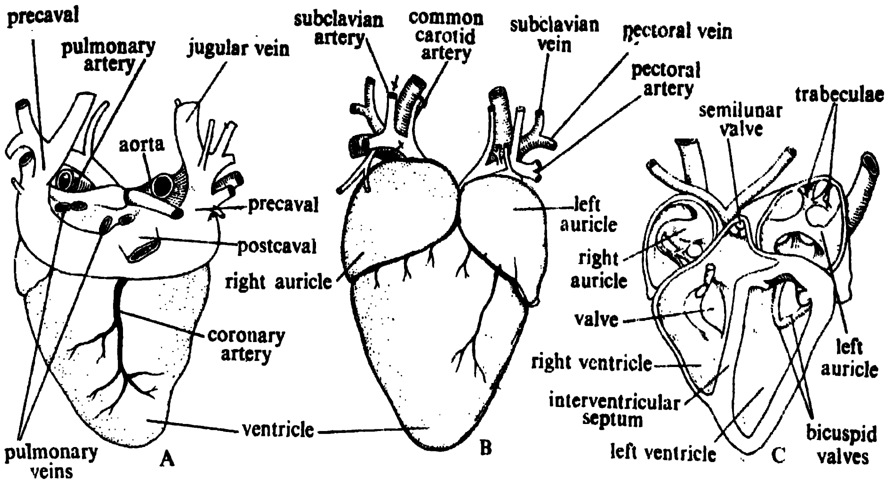

precaval
pulmonary artery
jugular vein
aorta
precaval
postcaval
right auricle
coronary artery
ventricle
pulmonary veins
A
subclavian artery
common carotid artery
subclavian vein
pectoral vein
pectoral artery
left auricle
right auricle
valve
right ventricle
interventricular septum
left ventricle
B
semilunar valve
trabeculae
left auricle
bicuspid valves
C

Fig. 8.14. Heart of *Columba*. A. Dorsal view. B. Ventral view. C. Longitudinal sectional view.

oxygenated blood to the different parts of the body. The right ventricle gives rise to pulmonary arch which carries deoxygenated blood to the lungs. The left ventricle is usually called the systemic ventricle and the right is called the pulmonary ventricle. The openings of the arches are guarded by three cup-like thick semilunar valves. The working of heart is controlled by elaborate intrinsic nervous system of heart. The wall of the right auricle bears *sinuauricular node* (or *pace-maker*) and the atrial septum bears *auriculoventricular node*. A special ring of *Purkinje fibres* is also present around right auriculoventricular wall. The rate of systole and diastole is much faster than other vertebrates.

Mechanism of circulation through heart. During the diastolic phase, the heart relaxes and the auricles receive blood from the veins. The right auricle gets the deoxygenated blood and the left auricle is filled up with oxygenated blood from the lungs via the pulmonary veins. The systolic action starts from the right auricle. It actually begins from the sinuauricular node and passes to the auriculoventricular node. This wave then spreads to the remaining parts of the heart. At the time of auricular systole, the blood comes to the ventricles through the auriculoventricular aperture. When the ventricles start contraction, the deoxygenated blood from the right ventricle is pushed to the lungs by the pulmonary arches. Single right aortic arch from the left ventricle conveys the oxygenated blood to the different parts of the body. The heart of pigeon is a double circuit heart and there is no chance of mixing up of oxygenated and deoxygenated blood except in the capillaries. This is a significant evolutionary advancement in birds over reptiles.

Blood vessels

The blood vessels include the arteries, veins and capillaries. The arteries supply blood to the different parts of the body and break up into *arterioles* and finally to finner anastomosing branches—the *capillaries*. The capillaries reunite to form the *venules* which ultimately form the veins.

Arterial system

The arterial system of pigeon comprises of the following aortae and their branches:

(1) An *aortic arch* originates from the left ventricle and then curves over the right bronchus. It reaches the dorsal body wall and then proceeds backwards as the dorsal aorta. (2) This right aortic arch, immediately gives rise to two stout *innominate* or *brachiocephalic arteries*. (3) Each innominate artery gives rise to *common carotid* and *subclavian arteries*. (4) Common carotid artery proceeds anteriorly along the ventrolateral side of the neck region ,and gives three branches: (*i*) *Internal carotid artery*. It runs up to the head region and supplies the brain. It gives another artery called the *descending oesophageal*. (*ii*) *Vertebral artery*. It goes to the vertebrarterial canal of

the vertebral column, supplies blood to the neck vertebrae and eventually goes to the brain. (*iii*) *Comes nervi vagi.* It runs anteriorly along the side of the vagus nerve and unites with the internal carotid artery. It sends one branch called the *ascending oesophageal artery* (Fig. 8.15). (*iv*) *External carotid artery.* This artery sends branches to the oesophagus and muscles of the head and palate. (5) *Subclavian artery.* The subclavian artery is a very stout vessel and gives rise to the following arteries: (*i*) *Internal mammary artery.* It supplies the ribs and sternum. (*ii*) *Pectoral artery.* This artery branches profusely and supplies the breast muscles. (*iii*) *Axillary artery.* This artery is the continuation of the subclavian artery in the arm pit or axilla. It gives off an artery to the shoulder and proceeds to the wing as the *brachial artery.*

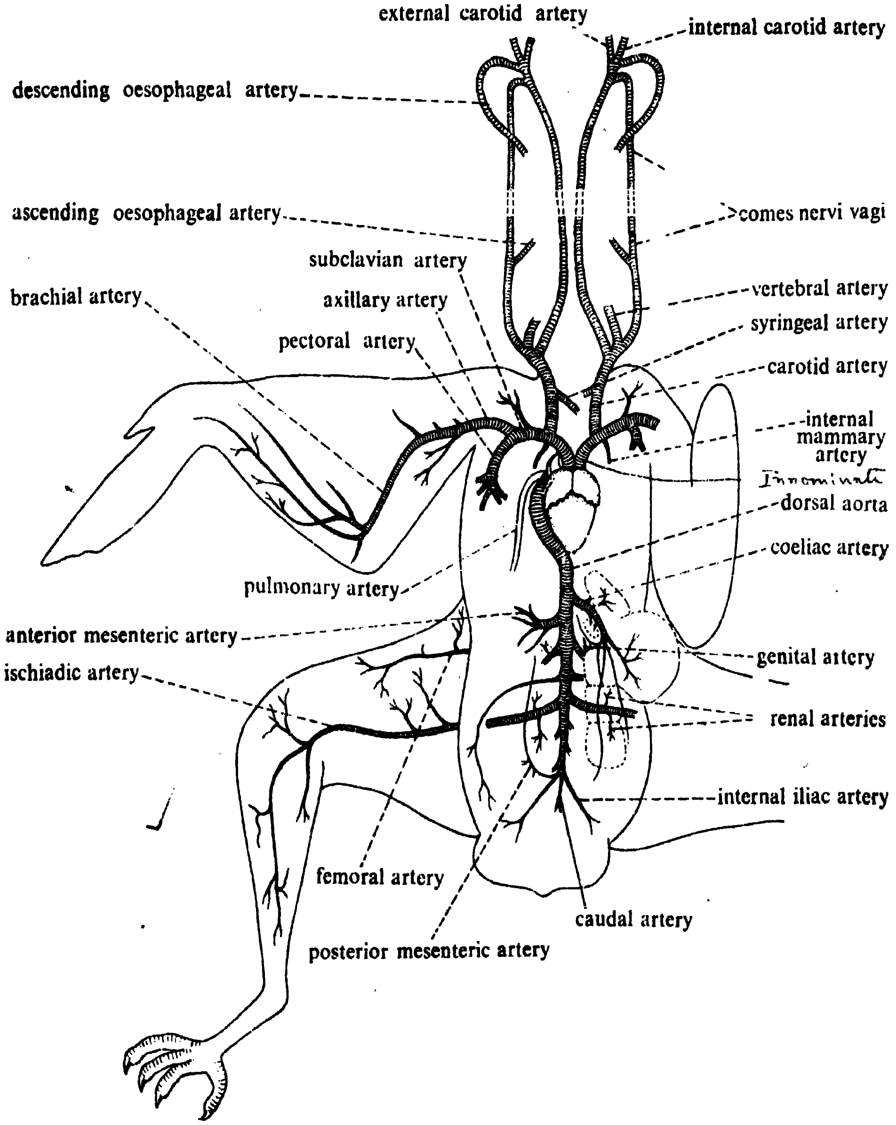

external carotid artery
internal carotid artery
descending oesophageal artery
ascending oesophageal artery
comes nervi vagi
subclavian artery
axillary artery
brachial artery
vertebral artery
syringeal artery
pectoral artery
carotid artery
internal mammary artery
Innominate
dorsal aorta
coeliac artery
pulmonary artery
anterior mesenteric artery
genital artery
ischiadic artery
renal arteries
internal iliac artery
femoral artery
caudal artery
posterior mesenteric artery

Fig. 8.15. Arterial system of *Columba*.

Dorsal aorta and its branches. The dorsal aorta runs along the middorsal wall of the body cavity and sends the following branches: (*i*) *Dorsal intercostal artery.* It supplies the intercostal muscles. (*ii*) *Coeliac artery.* It arises from the dorsal aorta as a single artery to the abdominal viscera. It gives a short *splenic artery* to the spleen. (*iii*) *Anterior mesenteric artery* supplies the small intestine. (*iv*) *Genital artery.* This artery supplies the gonad. In male, the testis gets the *spermatic artery*, while the female gets the *ovarian artery* to the ovary. (*v*) *Renal arteries.* The renal arteries comprise of three pairs of arteries supplying the three lobes of the kidney. (*a*) *Anterior renal arteries.* These paired arteries supply blood to the anterior lobe of the kidney. (*b*) *Median and posterior renal arteries.* Both these arteries are paired and supply the median and posterior lobes of the kidney. (*vi*) *Femoral artery.* These paired elongated branches pass through the kidney to supply blood to the proximal region of the hindlimbs. (*vii*) *Ischiadic artery.* This paired arteries supply blood to the posterior part of the hindlimbs. (*viii*) *Internal iliac artery.* The dorsal aorta divides posteriorly to form two internal iliac arteries, a posterior mesenteric artery and a single caudal artery. (*ix*) *Posterior mesenteric artery.* This single artery supplies the mesenteries of the posterior side. (*x*) *Caudal artery.* Single slender vessel originates as continuation of the dorsal aorta to supply to the tail region.

Pulmonary arch. The pulmonary arch arises from the right ventricle and immediately after coming out of the heart, it bifurcates to send pulmonary arteries to the lungs. The pulmonary arch conveys deoxygenated blood from the heart to the lungs for oxygenation.

Venous system

The venous system of pigeon is peculiar by showing the following characteristics: (*i*) Each lung gives out two pulmonary veins opening into the left auricle. (*ii*) Two precavals and one postcaval open directly into the right auricle (Fig. 8.16). There is no trace of sinus venosus. (*iii*) Considerable reduction of renal portal vein.

The veins in pigeon may be divided into three categories: Pulmonary, systemic and portal veins.

Pulmonary veins. The pulmonary veins constitute a very short circulatory circuit and carry oxygenated type of blood from the lungs. These veins enter the left auricle.

Systemic veins. Three principal systemic veins—two precavals and one postcaval drain deoxygenated blood from the capillaries of the body and open separately into the right auricle.

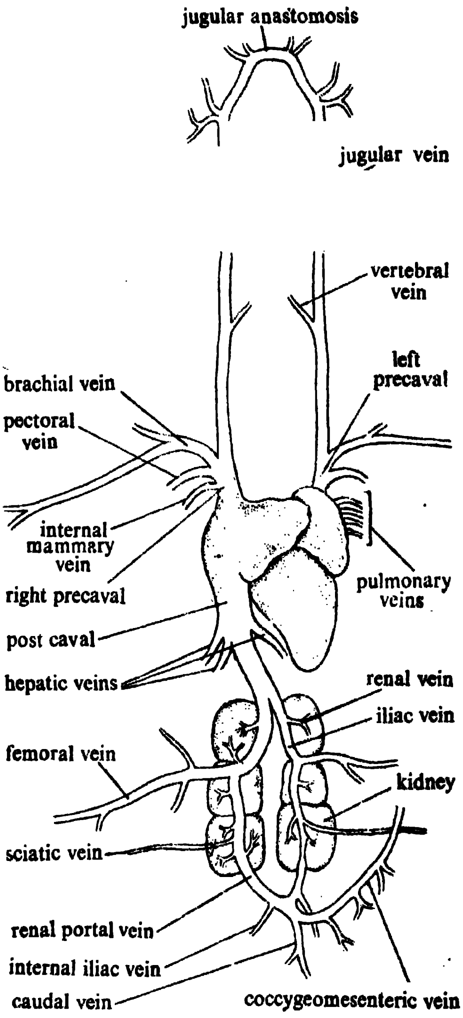


Fig. 8.16. Venous system of *Columba*.

Veins anterior to the heart. The paired precavals with all the veins opening into them are included under this category. Each precaval receives (*i*) *Jugular vein*, (*ii*) *Brachial vein*, (*iii*) *Pectoral vein* and (*iv*) *Internal mammary vein.*

Jugular vein. This vein receives several small veins from the crop and the shoulder, the vertebral vein and other veins from the head and neck. The *vertebral vein* brings blood from the vertebral column and spinal cord to jugular vein. The veins from the crop and shoulder are small and numerous. Their number and disposition are variable—so they are not given specific names. The left and right jugular veins are connected anteriorly by a small transverse connecting vein called the *jugular anastomosis*. This anastomosis gets veins from the veinous sinuses of the brain. This connection has a special importance for the mobility of the neck. The jugular vein receives *facial vein* (carrying blood from the skin and muscles of the head), *tracheal vein* (brings blood from the trachea), *cervical cutaneous vein* (originates from a plexus in the skin of neck) and *oesophageal vein* (gets blood from the oesophagus). These small veins are not shown in the diagram.

The precaval vein is formed by the union of the following three veins: *Brachial vein*. The brachial vein receives blood from the corresponding wing. Some small branches from the shoulder also open into it. *Pectoral vein*. This vein is formed by the union of profusely branched veins from the pectoral region. *Internal mammary vein*. This vein brings blood from the sternum, coracoid region and the ribs.

Veins posterior to the heart. The veins which are posterior to the heart include the following: *Postcaval vein*. This vein is formed by the fusion of two *iliac veins*. Each iliac vein is the continuation of the *femoral vein* bringing blood from the leg region. The femoral vein passes through the kidney tissue. The postcaval receives few *hepatic veins* from the liver and a small vein from

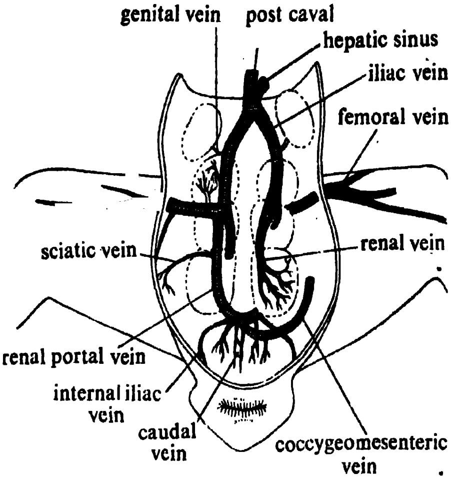

genital vein
post caval
hepatic sinus
iliac vein
femoral vein
sciatic vein
renal vein
renal portal vein
internal iliac vein
caudal vein
coccygeomesenteric vein

Fig. 8.17. Showing the abdominal veins of *Columba* except the hepatic portal veins.

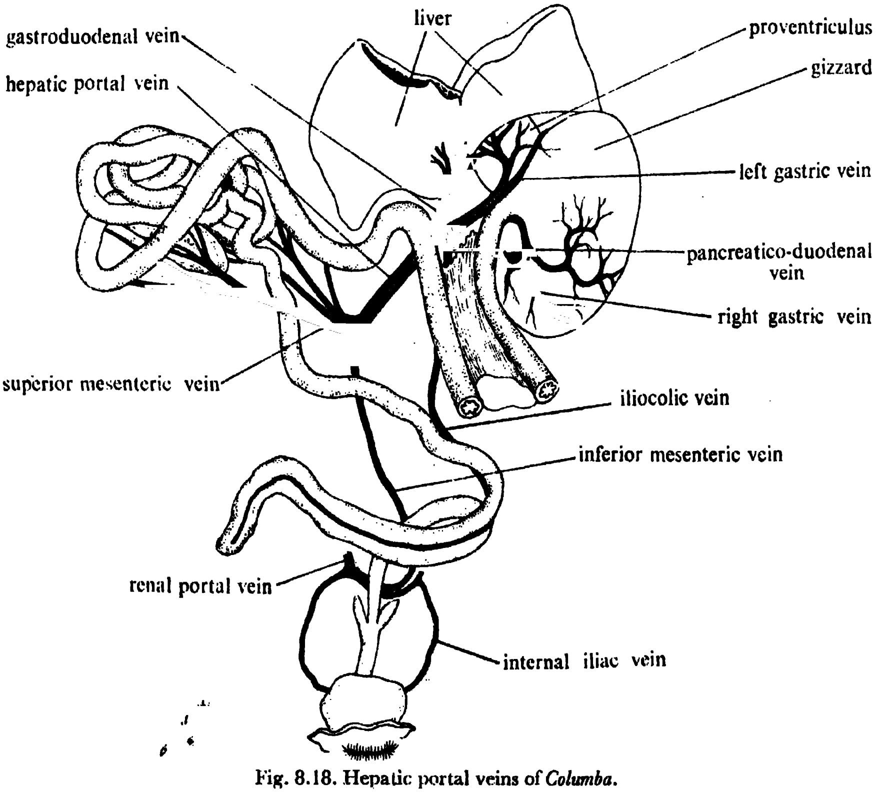

gastroduodenal vein
hepatic portal vein
liver
proventriculus
gizzard
left gastric vein
pancreatico-duodenal vein
right gastric vein
superior mesenteric vein
iliocolic vein
inferior mesenteric vein
renal portal vein
internal iliac vein

Fig. 8.18. Hepatic portal veins of *Columba*.

the ligament of the gizzard. *Genital veins* (*spermatic vein* in case of male and *ovarian vein* in female) are short veins which emptify to the iliac veins. *Renal veins.* These veins bring blood from the kidneys and open into the iliacs as well as into the renal portal vein. *Sciatic vein.* This vein from the thigh opens into the renal portal vein. *Internal iliac veins.* These paired veins bring blood from the dorsal pelvic region. *Caudal vein.* This small vein comes from the uropodium. *Coccygeomesenteric or inferior mesenteric vein.* This vessel runs anteriorly in the mesentery to participate in the hepatic portal system. It also gets branches from the rectum. The blood from this vein also flows to the renal portal vein. (Fig. 8.17).

Portal veins. The hepatic and renal portal veins are also considered under the posterior veins. The *renal portal vein* originates at the junction of the coccygeomesenteric, internal iliac and caudal veins. Each renal portal vein passes through the kidney tissue of that side and opens into the femoral vein and also receives sciatic vein. The renal portal vein is peculiar, because it never breaks up into capillaries in the kidney, but sends off a few small branches. Small renal veins open to this vessel. The *hepatic portal vein* forms an elaborated system. This system drains blood into the liver from the abdominal viscera (Fig. 8.18). The hepatic portal system includes: *Gastroduodenal vein* which is formed by the *pancreatico-duodenal vein* and *left gastric vein.* The pancreatico-duodenal vein also gets a vein from the last part of the small intestine and the *right gastric vein.* The mesenteric veins are included under this system.

Lymphatic system

The lymphatic system is well-developed and elaborated. Numerous *lacteal vessels* emerged from the small intestine. These vessels unite to form paired *thoracic ducts.* These ducts eventually open into the precaval veins.

NERVOUS SYSTEM

The nervous system of pigeon is divisible into (1) Central Nervous System, (2) Peripheral Nervous System and (3) Autonomous Nervous System.

Central Nervous System. The central nervous system includes the brain and the spinal cord.

Brain. The brain of pigeon is peculiar for its short and rounded form. It is built upon the same structural plan as that of other vertebrates. The brain is covered by two meninges, an inner *pia mater* and an outer *dura mater.* The *olfactory lobes* are poorly developed and form the most anterior part of the brain (Fig. 8.19A). The *cerebral hemispheres* are large, situated just posterior and dorsal to the olfactory lobes. The cerebral hemispheres consist largely of *corpora striata* (Fig. 8.19D). The corpora striata are composed of solid mass of tissue and control the reflex behaviours of the animal. Each corpus striatum is differentiated into three regions -the upper portion is called the *hyperstriatum,* the lateral region as the *mesostriatum* and the lower part as the *palaeostriatum.* The roof of each cerebral hemisphere is called the *neopallium.* The neopallium is unconvoluted. The cerebral hemispheres become expanded posteriorly to meet the cerebellum.

The *diencephalon* is inconspicuous and remains completely covered by the cerebral hemispheres and cerebellum. From the *hypothalamus,* a *hypophysis* arises. On the roof of the diencephalon, a small pineal body projects between the cerebral hemispheres and cerebellum.

The *optic lobes* are large in size and spherical in shape. They are pushed to the lateral side due to the backward growth of the cerebral hemispheres. The *optic nerves* are prominent and form *optic chiasma* (Fig. 8.19B) situated ventral to the midbrain. A major portion of the optic nerves passes into the thalamus and the rest to the midbrain. The midbrain as well as the thalami have reciprocal connections with the corpus striata of the cerebral hemispheres.

The *cerebellum* is highly developed and consists of a large central *vermis* and two small lateral lobes, the *flocculi.* Transverse grooves are present on the surface of the vermis. The over development of cerebellum is possibly connected with the control of movement and the precise timing during flight. Like that of other vertebrates, pigeon possesses both spino-cerebellar and vestibulo-cerebellar nerve tracts. In addition to these two tracts, tecto-cerebellar and strio-cerebellar tracts are present. The cerebellum is solid, because the fourth ventricle does not extend into it. The *medulla oblongata* has a prominent ventral fissure.

The *lateral ventricles* are greatly reduced and represented by small crescent-shaped cavities located at the posterior end of cerebral hemispheres. The *third ventricle* (Fig. 8.19D) is a small slit-like cavity situated posterior to the corpus striatum. The lateral ventricles and the third ventricle are communicated by *foramen of Monro*. Each optic lobe contains an extension from the *aqueduct of Sylvius*, a narrow passage contained in the midbrain connecting the third ventricle with the fourth

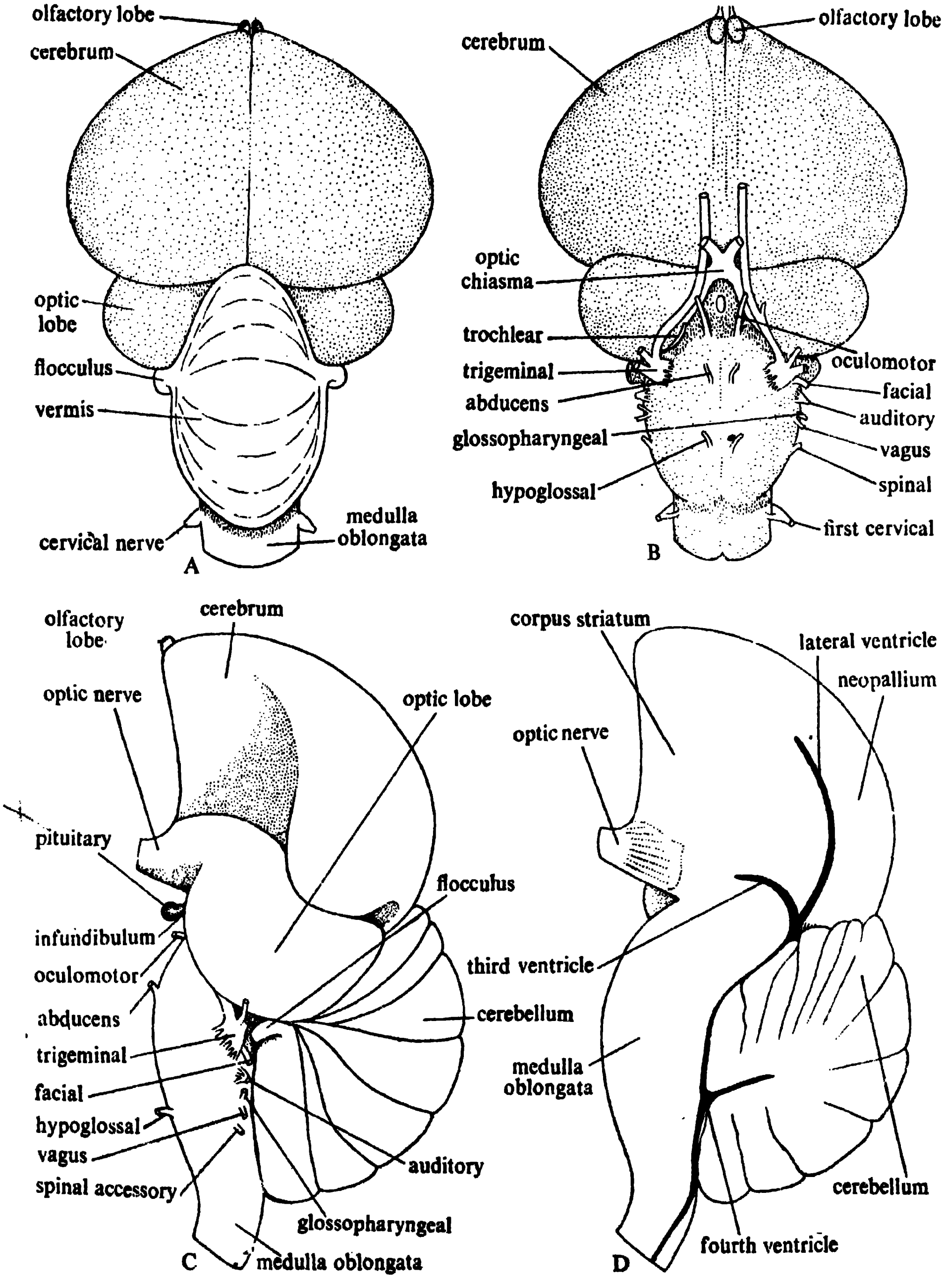

olfactory lobe
cerebrum
optic lobe
flocculus
vermis
cervical nerve
medulla oblongata
A
olfactory lobe
cerebrum
optic chiasma
trochlear
trigeminal
abducens
glossopharyngeal
hypoglossal
oculomotor
facial
auditory
vagus
spinal
first cervical
B
olfactory lobe
cerebrum
optic nerve
optic lobe
pituitary
flocculus
infundibulum
oculomotor
abducens
trigeminal
facial
hypoglossal
vagus
spinal accessory
third ventricle
cerebellum
auditory
glossopharyngeal
medulla oblongata
C
corpus striatum
lateral ventricle
neopallium
optic nerve
medulla oblongata
cerebellum
fourth ventricle
D

Fig. 8.19. Brain of *Columba*. A. Dorsal view. B. Ventral view. C. Lateral view. D. Sagittal sectional view.

ventricle. The *fourth ventricle* is a small cavity between the cerebellum and medulla oblongata.

Spinal cord. The spinal cord is covered by pia mater and dura mater like the brain. Along its length, the spinal cord is enlarged in the *cervical* and *lumbosacral* regions. Each such enlargement gives origin to a pair of plexi which in turn send nerves to the limbs. In the region of the lumbosacral enlargement, the cavity becomes expanded to form a diamond-shaped cavity called the *sinus rhomboidalis*. This cavity is filled with a fatty substance.

Peripheral Nervous System. The cranial and spinal nerves constitute the peripheral nervous system. This system is essentially same as in *Calotes* (*vide* pages 254 and 255) already described. There are 12 pairs of **cranial nerves** emerge out of the brain. Fig. 8.20 shows the origin and distribution of the trigeminal (V) and facial (VII) cranial nerves. The trigeminal originates by many roots from the lateral part of medulla oblongata ventral to the optic lobes. It has three branches: ophthalmic, maxillary and mandibular. The trigeminal nerve passes through the orbital fissure. The facial nerve, after arising from the lateral surface of medulla but posterior to trigeminal sends nerves to the pharynx and muscles of mastication. Fig. 8.21 represents the origin and distribution of glossopharyngeal (IX) and vagus (X) nerves. The glossopharyngeal originates superficially from the lateral surface of the medulla posterior to the auditory nerve and comes out of the cranium through a small foramen between ear and hypoglossal foramen. It sends branches to palate, pharynx, larynx and taste-buds on the tongue. The vagus nerve originates from the lateral side of the medulla, posterior to glossopharyngeal. The main nerve trunk runs posteriorly along the neck region adjacent to jugular vein. Near the brachial plexus it sends branches to the oesophagus and crop. The main trunk sends branches to heart, lungs and abdominal viscera. The spinal accessory (XI) is a motor nerve supplying nerves to the neck muscles. The hypoglossal (XII) nerve arises from the ventral surface of the medulla posterior to

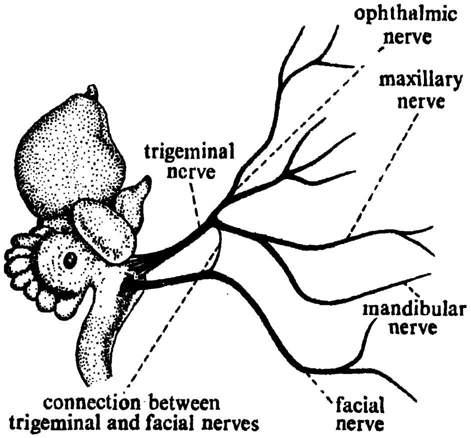

ophthalmic nerve
maxillary nerve
trigeminal nerve
mandibular nerve
connection between trigeminal and facial nerves
facial nerve

Fig. 8.20. Showing the origin and distribution of the fifth and seventh cranial nerves of *Columba*. The branches are drawn apart.

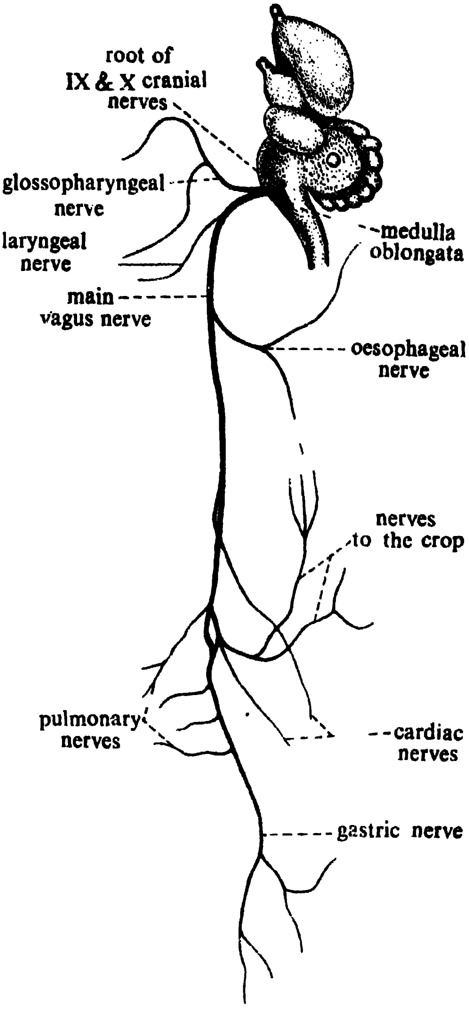

root of IX & X cranial nerves
glossopharyngeal nerve
laryngeal nerve
main vagus nerve
medulla oblongata
oesophageal nerve
nerves to the crop
pulmonary nerves
cardiac nerves
gastric nerve

Fig. 8.21. Showing the origin and distribution of the ninth and tenth cranial nerves of *Columba*.

abducens nerve and passes through the hypoglossal foramen just lateral to the occipital condyle. If sends branches to the neck and tongue muscles.

Spinal nerves. There are thirtyeight pairs of spinal nerves in pigeon. These nerves are named according to the zones of the vertebral column from which they arise. They are: *cervical*, *thoracic*, *lumbosacral* and *caudal nerves*. The number of the spinal nerves in each region are: Cervical = twelve pairs, thoracic = eight pairs, lumbosacral = twelve pairs and caudal = six pairs.

On each side, first nine cervical nerves serve the neck musculature, while the last three cervical together with first two thoracic nerves form the brachial plexus. This plexus gives rise to (1) *Brachialis superior* to the wing and (2) *Brachialis inferior* to the pectoral muscles, membrane between radius and ulna and posterior border of ulna. Third to seventh thoracic nerves innervate the body and spinal muscles. The eighth thoracic nerve and the first lumbosacral nerve form the lumbosacral plexus. It gives branches to the muscles of the hip and hindlimbs. The last three lumbosacral nerves and the six caudal nerves serve the tail muscles.

Autonomous Nervous System. It includes the *sympathetic cords*, one passes over the ventral surface of the ribs and the other passes dorsal to each rib. In between the ribs these two cords become fused. The nerves from the sympathetic cords between the third and fourth, fourth and fifth, fifth and sixth thoracic nerves together with a branch from the sympathetic ganglion join to form the *coeliac plexus*. Two small autonomic nerve trunks run posteriorly to the cloaca and adjoining viscera. The vagus belongs functionally to the sympathetic nervous system.

SENSE ORGANS

Pigeon possesses well-developed special sense organs to receive external stimuli.

Olfactory organs. These paired organs are present near the base of the upper beak. Each olfactory chamber is covered externally by *ectoethmoid* which is drawn into three spiral processes called the *turbinals* to increase the surface area of the mucous membrane. The olfactory chambers are separated by *mesethmoid*. Each chamber is divisible into an anterior nonsensory part called the *vestibule* and a posterior sensory part. The vestibule has many layered epithelial lining but the posterior part is lined by only one layered epithelium with innervations from olfactory nerves. The power of smell is very poor.

Eyes. The eyes are well-developed and built on the typical vertebrate plan. They are extremely large in size. The shape of the eye-ball is not spherical but has the form of a biconvex lens. The lens and cornea bulge forwards and the shape is maintained by a ring of bony *sclerotic plates*

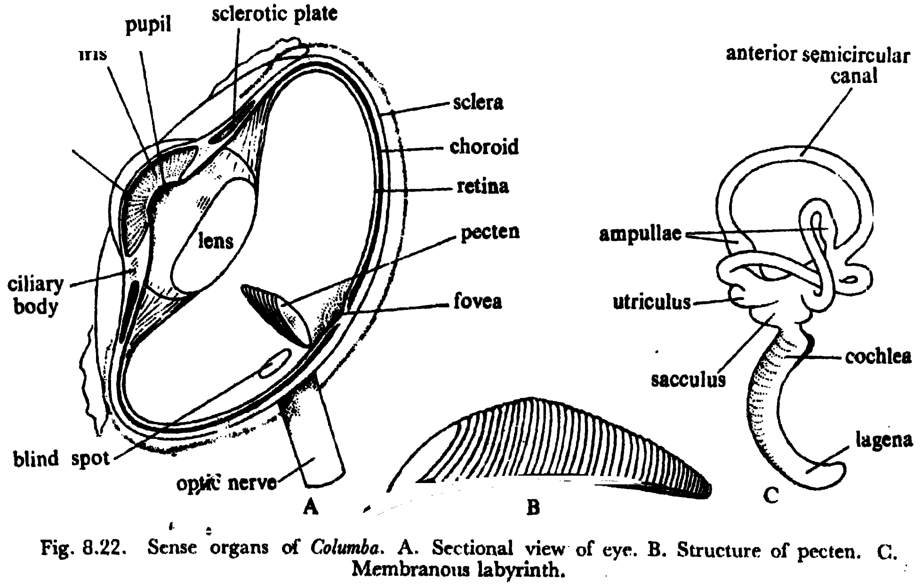


Fig. 8.22. Sense organs of *Columba*. A. Sectional view of eye. B. Structure of pecten. C. Membranous labyrinth.

present in the *sclera* (Fig. 8.22A). The sclera is a tough, white fibrous outer layer of the eyeball. The anterior transparent continuation of the sclera is called the *cornea.* The *choroid* is the black pigmented layer situated just internal to the sclera. The *iris* is the pigmented partition pierced by the *pupil* at the centre. It separates the anterior and posterior chambers of the eye. The iris is the anterior continuation of the choroid and composed of striated muscles. The posterior chamber is bordered anteriorly by the iris and is filled with *vitreous humour* while the anterior chamber bordered anteriorly by the *cornea* and posteriorly by the lens. The chamber is filled with *aqueous humour.* The vitreous body is a jelly-like mass and the aqueous humour is watery. The *lens* is a soft elliptical body which remains suspended from the ciliary body by ligaments. Accommodation is effected by changing its shape by the pressure exerted upon it by the ciliary muscles behind. The *ciliary body* is the enlargement of the choroid containing striated muscle which controls the lens. The ciliary muscle is divided into anterior (Crompton) and posterior (Brucke) portions. The *Brucke's muscle* draws the lens forward into the anterior chamber and the *Crompton's muscle* is so oriented as to pull on the cornea. By its action, the radius is shortened and assists in accommodation. The retina is a light coloured tissue internal to the choroid. It is composed of *cones* and *rods.* The retina contains a depressed area called the *fovea* which is the region of acute vision in bright light. The *blind spot* is the point of exit of the optic nerve from the retina. Projecting into the vitreous body from the blind spot, a characteristic structure called the *pecten* is present (Fig. 8.22B). The pecten is highly variable in size and shape in different birds. In pigeon it is composed of a thin dark pigmented plate. This plate is folded fanwise and assumes the form of a comb. It is a made up of a vascular network supported by pigmented glial cells. The pecten is an enigmatic organ in avian eye and its physiological role is not yet ascertained. This structure is claimed to perform a number of functions in the life of pigeon. The functions are: (1) As the pecten is an erectile structure, it is possible that irregular shadow cast by this organ provides many blind spots on the retina. This action enhances the on-and-off effects in the visual field and thus increases the acuity of visual perceptions. (2) The pecten is a highly vascular structure and provides nutrient substances to the vitreous body and retina. (3) The pecten protects the retina from strong light and also (4) serves to warm the eye. It has long been claimed that pecten is in some way concerned with the process of accommodation, it is not likely that the pecten actually helps in the process. The accommodation is actually done by the action of the ciliary bodies.

There are glands associated with the eyes. The *lacrymal gland* is situated at the ventral margin of the orbit. The *Harderian gland* is located on the anterodorsal surface of each eye. The movement of each eye ball is controlled by *superior oblique*, *superior rectus*, *internal rectus*, *inferior oblique*, *external rectus*, *inferior rectus*, *quadratus* and *pyramidalis muscles.* The upper and lower eye-lids are present. The third eye-lid, *nictitating membrane* is prominent.

Ear. The ear contains three usual divisions—the external, middle and internal ear. The external ear is represented by a tightly stretched circular skin called the tympanic membrane. It remains hidden by feathers and the *external auditory meatus* is found by probing just posterior to the angle of the jaw. The middle ear is tubular and its cavity is connected with the pharynx through an eustachian tube which equalises the air pressure on the two sides of the tympanum. Within the middle ear cavity there is a rod-like *columella* with its process called the *extracolumella* which conveys the sound waves to the internal ear. The internal ear contains a small *membranous labyrinth* which is enclosed within a *bony labyrinth.* The foot plate of the columella fits into the *fenestra ovalis.* Both the vestibular as well as auditory parts of the internal ear are well-developed. The vestibular part is peculiar by having connections with the cerebellum which suggests its importance in flight. The anterior semicircular canal is the largest of the three canals. The auditory part is greatly developed. There is a distinct cochlea which encloses a *basilar membrane.* This membrane contains many fibres bearing *hair cells.* Another aggregation of hair cells together with calcareous particles is present at the apical end of the cochlea. The cochlea bears an extended *lagena* which is responsible for receiving the low pith sounds (Fig. 8.22C).

Miscellaneous Sense Organs

Besides the three pairs of special sense organs, there are many other receptors for external stimuli. The *Grandy's corpuscles* present in the skin of the beak are touch receptors. The *Herbst's corpuscles* present in the dermis are numerous and are vibration and heat receptors. Chemoreceptors for smell are little developed. There are few *taste-buds* on the tongue.

ENDOCRINE SYSTEM

The endocrine system is well-developed in pigeon. Following are the endocrine organs belong to the endocrine system.

Thyroid gland.

These paired glands are present one on each side of the trachea near the junction of neck and trunk. The thyroid hormone, *thyroxin* regulates the general metabolism and the periodic moulting of pigeon. The functioning of thyroid glands is controlled by the thyroid stimulating hormone of the anterior pituitary.

Parathyroid glands

These paired glands are present near the close vicinity of thyroids. These are small in size and control the calcium and phosphate metabolism of the body.

Thymus glands

These paired glands are present on the sides of the throat. They are well-developed and elongated in young stage. They become greatly reduced in matured adult. The physiological function of these glands is not properly ascertained. It is believed to be associated with the growth of the animal.

Adrenal or suprarenal glands

These paired glands are prominent yellowish bodies, situated anterior to the kidneys. Each gland is irregular in shape and is composed of *chromaffin tissue* intermingled with fatty tissue. The secretion of the adrenal gland, *adrenalin* controls the vital functions of the animal.

Pituitary gland

This highly specialised gland remains within a skeletal cage formed by the sphenoid bone. This inner skeletal cage is called the *sella turcica*. The pituitary gland possesses two major divisions—(*i*) *adenohypophysis* (originates from the roof of the embryonic mouth cavity) and *neurohypophysis* (arises from the floor of diencephalon). The adenohypophysis is subdivided into three parts—*pars distalis, pars tuberalis* and *pars intermedia*. The neurohypophysis has two subdivisions—*lobus nervosus* and *infundibulum*. The pars distalis represents the anterior pituitary and the pars intermedia and lobus nervosus constitute the posterior pituitary. The pars tuberalis together with infundibulum constitute the stalk of pituitary gland. The bipartite lobes of the anterior pituitary secrete different hormones like gonadotrophins, adrenocorticotrophin, thyrotrophin, prolactin, etc. Various external stimuli influence the secretory activities of the anterior pituitary.

Islets of Langerhans

The pancreas contains endocrine islets of Langerhans. These islets discharge *insulin* into the blood stream.

Gonads

The gonads, besides their normal function of producing gametes, secrete sex hormones. The testes secrete *testosterone* and the ovary produces the *oestrogen*. The testosterone is secreted by the interstitial or Leydig cells of testis and controls the growth of sex organ and secondary sexual characters. The oestrogen regulates the secondary sexual characters and the behaviour of the bird.

EXCRETORY SYSTEM

The excretory system comprises of a pair of kidneys and a pair of ureters opening into the cloaca. Absence of urinary bladder is a notable feature in the anatomy of pigeon.

Each *kidney* is a flattened body which is divided into three lobes. These kidneys are of metanephric type and remain closely fitted into the dorsal wall of the pelvis. The nephrons are highly specialised. The glomeruli are supplied by renal artery and the loop of Henle is quite extensive. This loop helps to reabsorb water from the glomerular filtrate. The urine contains little quantity of water with high concentration of uric acid precipitate.

Each *ureter* originates from the first and second lobes of the kidney and passes down to open into the middle chamber (urodaeum) of the cloaca. The urine is voided with the faeces.

REPRODUCTIVE SYSTEM

The sexes are separate. Sexual dimorphism is absent in pigeon.

Male reproductive system

The male reproductive system includes two *testes* and two *vasa deferentia* (Fig. 8.23B). Each testis is an ovoid body which is attached to the anteroventral end of the kidney by a fold of peritoneum called the *mesorchium*. The size of the testes varies greatly according to the season. The testes are composed of numerous coiled *seminiferous tubules*. Between the tubules, groups of Leydig cells are present.

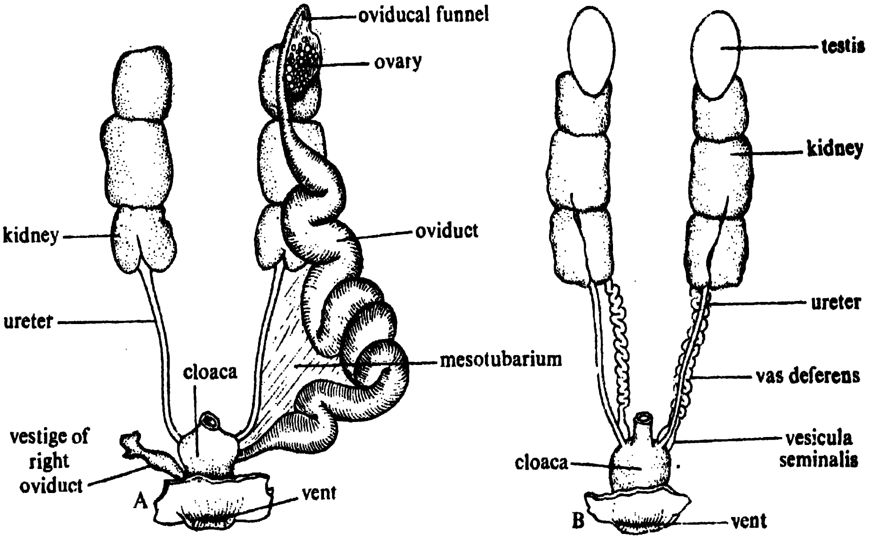


Fig. 8.23. Urinogenital system of *Columba* A. Female. B. Male.

From the inner side of each testis originates a much coiled duct called the vas deferens. Each vas deferens runs posteriorly parallel with the ureter and opens into the urodaeum at the tip of a small papilla. These papillae are slightly erectile and constitute the miniature copulatory organs of many birds. The last part of the vas deferens becomes slightly swollen to form *seminal vesicle*. Typical copulatory organs, observed in other vertebrates, are absent in pigeon.

Female reproductive system

The female reproductive system is peculiar by having only left *ovary* and left *oviduct* (Fig. 8.23A). The right ovary and oviduct are atrophied in adult. The left ovary is large and contains eggs of various sizes. The ovary is suspended to the dorsal body wall by a short mesentery called the *mesovarium*. The left oviduct is long and is attached with the dorsal body wall by *broad ligament* or *mesotubarium*. The anterior end of the oviduct opens to the coelom by an expanded funnel-like opening called the *oviducal funnel* or *ostium*. The remaining part of the oviduct is thick, muscular and coiled. Various glands are present in the inner lining of the oviduct. When an ovum is matured, the ovarian follicle bursts to liberate the ovum. The ovum enters into the cavity of the oviduct through the oviducal funnel. While passing down the oviduct, the ovum (fertilized or unfertilized) is invested by the secretion of the various glands. The left oviduct opens into the urodaeum. A small vestigial right oviduct is found on the right side of the urodaeum.

Insemination and egg laying. Fertilization is internal. Insemination is done when the proctodaea of both the sexes are everted and brought close together in a state of "cloacal-kiss'. During this act, the sperms are ejected into the female tract which travel up to fertilize the egg. Two eggs are generally laid at one time in pigeon. These eggs are incubated by the parents for a fortnight at a temperature of 38° to 40°C.

When the development is completed, young bird breaks the shell and comes out of the egg. The young is nourished by the parents with the pigeon's milk.

Structure of egg. The egg is large due to the accumulation of great quantity of yolk material. The protoplasm forms a small round area called the *germinal disc* (blastodisc) containing the ovum. As it passes down the oviduct, a coat of thick *albumen* is accumulated and the disc becomes pushed to the upper side. As the egg rolls during its transit, the albumen becomes coiled at the two sides to form twisted cord—the *chalaza*. In addition, more fluid albumen is deposited. Then a tough *shell membrane* and a *calcareous shell* are added by the secretory activities of the glands present in the oviduct. The shell membrane is parchment-like and composed of two layers which enclose an *air-space* at the broad end of the egg. (Fig. 8.24). The shell is usually white in colour which may be coloured due to the deposition of special pigments. The shell consists of three layers and is provided with vertical pore canals.

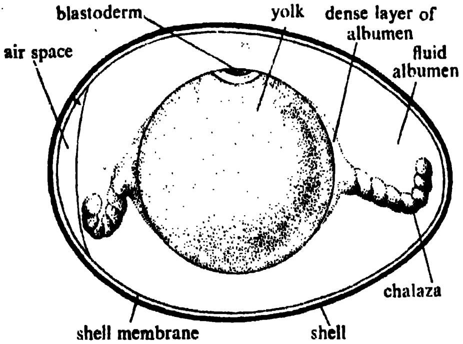


Fig. 8.24. Structure of egg of *Columba*.

FLIGHT MODIFICATIONS IN PIGEON

Pigeon is a typical representative of flying birds. This animal exhibits peculiar anatomical modifications for leading a life in air. It shows actually double adaptations—aerial and cursorial and/or scansorial. As a consequence, the forelimbs have converted into the wings and the hindlimbs have virtually retained the reptilian plan and have undergone less modification.

To fly in air, a heavier-than-air organism must possess the following unavoidable prerequisites, without which the volant life becomes impossible. The prerequisites are: (1) Organs for flight, (2) Lightness and rigidity, (3) Evolution of extra energy with provision for high power, (4) Speed and (5) Balancing and control. Let us now consider the ways how pigeon has modified itself to lead a perfect life in air.

Organs for flight. The forelimbs have transformed into the wings. The wings are the sole organs for flight. These organs have complicated structural constructions consisting of a frame work of bones, muscles, nerves, blood vessels, feathers, etc. The humerus is a strong long bone with a prominent ridge for the insertion of the flight muscles. The radius is a nearly straight and slender bone. The ulna is stouter and slightly curved. Only three digits are present. There is no trace of fourth and fifth digits. The small bones of the waist, hand and fingers have become highly modified both by the loss of bony units and by the fusion of the remaining pieces into strong bony complexes. Such a fusion reduces the chance of dislocation and mechanical friction during action.

The wings spring from the anterior region of the trunk. During rest the wings remain folded against the sides of the body. During flight the wings become expanded. The surface area of the wings is increased by the development of feathers. The patagia are vestigial. A fold of skin stretches between the upper arm and the fore arm which is called the *alar membrane* or *prepatagium*. A similar but smaller fold extends between the trunk and the proximal portion of the upper arm. There are twenty three remiges in pigeon, of which eleven are primaries and twelve are secondaries. The interstices between the quills of the remiges are closed by several rows of coverts to make the wing a continuous area to oppose the buoyancy of air. The lower surface of the wings is concave while the dorsal side is convex. This makes the downstroke of the wings more powerful.

The action of the wings is controlled by the flight muscles. The muscle fibres composing the muscles are long and striated to withstand fatigueness after prolonged activity. The important flight muscles are (1) *Pectoralis major*. The powerful downstroke of the wing is caused by this immense muscle. (2) *Pectoralis minor*. The elevation of the wing is caused by this muscle. (3) *Coracobrachialis muscles*. These small muscles aid in depressing the wing. (4) *Tensores patagialis muscles* help to keep the patagia tensely stretched when the wings are extended. The flight muscles are highly vascularised structures. The subclavian artery is very stout and divides into two branches: a pectoral artery to supply the flight muscle and an axillary artery to the wing.

Lightness and rigidity. The skeletal framework of pigeon is very stout. It has attained mechanical perfection by using all possible architectural principles to get maximum strength and rigidity. Many bones are either rod-like or 'T'-like. The sternum is a typical 'T'-like bone. Besides the typical long bones, the coracoid is a stout rod-like bone to withstand the pressure of the flight muscles. The long bones are pneumatic (Fig. 8.25) and provided with a secondary plastering to make them rigid.

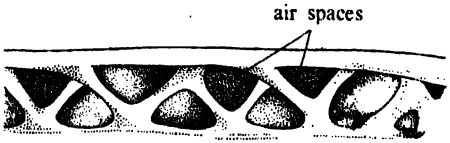


Fig. 8.25. Showing the pneumatism in the metacarpal of a flying bird.

The skull bones are paper-like thin. These bones are firmly fused with each other. The posterior portion of the skull is spongy. Development of air sacs causes the body light, because these sacs contain warm air to lighten the specific gravity of body. Although the vertebral column is well differentiated, the vertebrae (particularly towards the posterior region) show the tendency of fusion. The synsacrum and pygostyle are typical examples of such fusion of posterior vertebrae. Absence of gall bladder, urinary bladder, right ovary and oviduct (in female) minimise the body weight to some extent.

Extra energy and power. The secret of obtaining great and sustained power lies in the ability to convert chemical energy into mechanical motion. This is done through rapid and complete combustion of fuel. In living organism this energy is liberated by the respiratory system. The lungs are proportionately smaller, but the efficiency is increased by the development of air-sacs that are developed from the lungs. The exchange of gases is very perfect in birds and the air-sacs help to convey oxygen directly to many tissues. The body temperature is higher which enhances the rate of combustion. The nonconducting coat of feathers prevents the surface loss of heat. Crude power in the form of stored food grains is stored in the crop. The circulatory system as a whole is very efficient with a large and powerful heart.

Attainment of speed. Speed is a must for aerial life. The body is fusiform and lacks any extra projection which may offer resistance in the attainment of speed in air. Insertion of air-sacs in between the flight muscles like pads reduces mechanical friction and increases the mobility in muscular action.

Maintenance of balance and steering: An efficient equilibrating device is necessary for balanced flight. To equalise irregularities of air pressure on the two wings, pigeon can decrease the surface area of the wing by partially flexing. The air-sacs are so arranged on the two sides of the body, a proper centre of gravity is easily restored by shifting the contained air from one side of the body to the other. Most of the heavier visceral organs are lodged in the pelvis to maintain a proper centre of gravity. The tail is provided with rectrices and acts as steering during flight. The brain is well developed with a special development of cerebellum. The optic lobes are well-formed. The organs for vision are highly specialised to have acute power of vision. To have a wide visual field, the head can be rotated through an angle of 180° due to the possession of heterocoelous neck vertebrae. The jugular veins are long with an anterior jugular anastomosis.

SOME INTERESTING BIRDS

The class Aves is represented by about 8,650 species of living birds. In India about 1,200 species of birds have been recorded today. The variety of climatic conditions and ecological habitats in India has resulted in the occurrence of such a high number and diversity of forms for a single country. Some common Indian birds are noted below:

WHITEBACKED VULTURE (*Gyps bengalensis*). This species (Fig. 8.26A) of vulture is commonly found in all parts of India. It has an ugly and repulsive appearance. This species lives either singly or in groups. They devour carcases and are beneficial to man.

SPOTTED OWLET (*Athene brama*). This species of owl (Fig. 8.26B) is the most familiar bird in this country. It lives mainly on insects, lizards, small birds and small rodents. The digits of the hindlimbs and the beak become modified for the purpose of catching the prey. Owl is a nocturnal bird, i.e., it spends the daytime hidden in secluded leafy branches or tree-holes and becomes very active during the night. By nature these birds are noisy and produce chattering, chuckling and squabbling notes specially heard during dusk. Owls prefer to live in the plains and foothills near human habitation. The head is large and spherical with forwardly directed conspicuous eyes. The ear opening is large with flap-like cover resembling mammalian pinna.

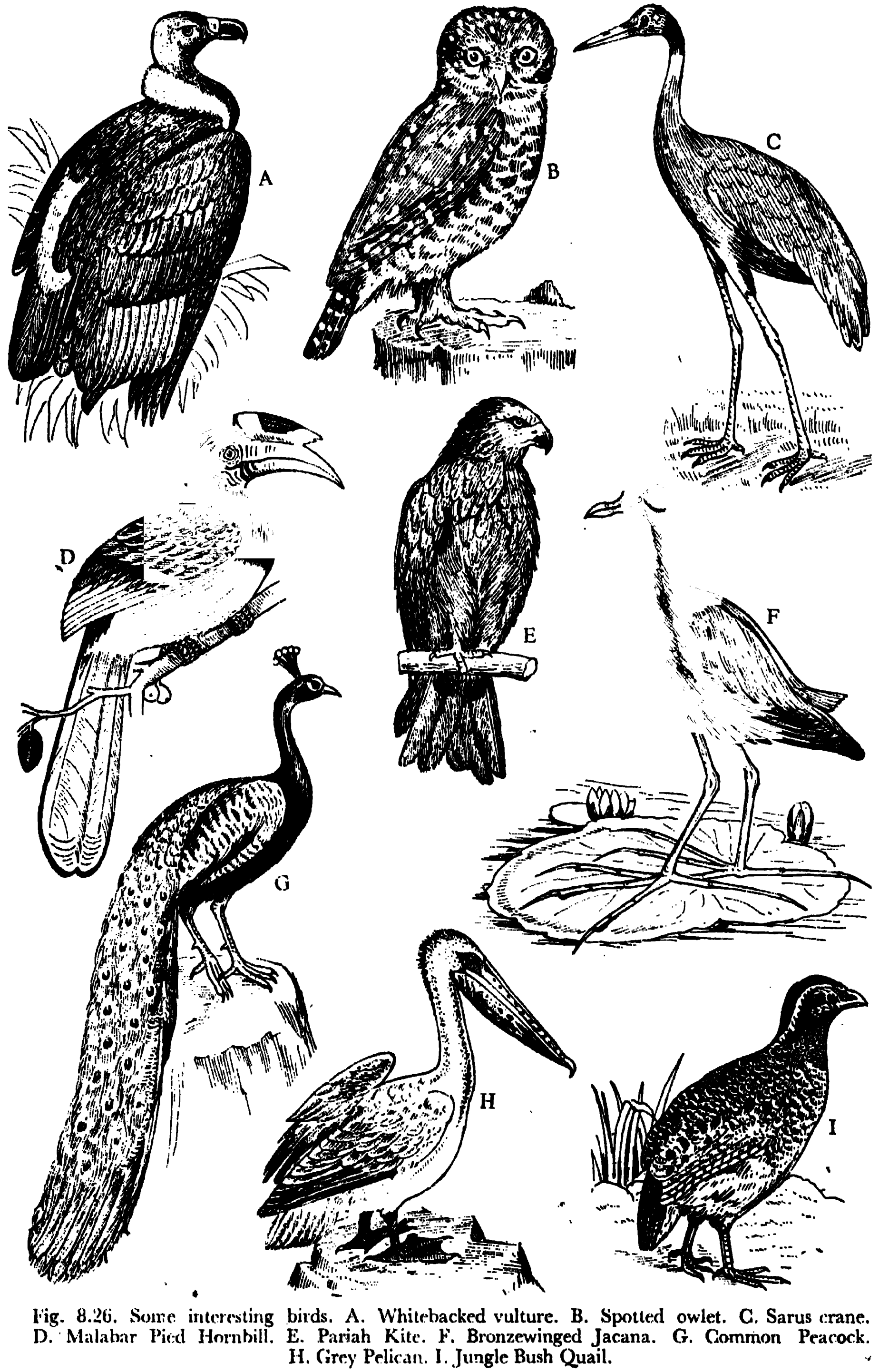


Fig. 8.26. Some interesting birds. A. Whitebacked vulture. B. Spotted owlet. C. Sarus crane. D. Malabar Pied Hornbill. E. Pariah Kite. F. Bronzewinged Jacana. G. Common Peacock. H. Grey Pelican. I. Jungle Bush Quail.

SARUS CRANE (*Grus antigone*). This bird is the largest crane (Fig. 8.26C) inhabiting essentially the well-watered open plains of India. They are omnivorous, i.e., eat vegetable matters, insects, snails, amphibians, fishes, etc. This species is notable for exhibiting extravagant courtship displays during breeding season.

MALABAR PIED HORNBILL (*Anthracoceros coronatus*). This is a popular hornbill called as the *Dhanesh*. It is basically a fruit-eater and found in fruit-laden trees of South and Central India, parts of Orissa, Bihar and Uttar Pradesh. Dhanesh is a heavy-billed arboreal bird (Fig. 8.26D).

PARIAH KITE (*Milvus migrans*). This bird is commonly called the *Cheel*. It is found perched on tree-tops, roof-top or fly in air. It possesses a forked tail (Fig. 8.26E) and is coloured brown. It is also a scavenger and usually eats small dead animals.

BRONZEWINGED JACANA (*Metopidius indicus*). This is a common Indian waterbird inhabiting tanks and jheels. The toes are extremely elongated to ski over the floating leaves (Fig. 8.26F). It is a poor flyer and lives on small aquatic weeds, fishes and molluscs.

COMMON PEACOCK (*Pavo cristatus*). This bird has a gracefully coloured appearance and commonly named as *Mayur*. *Pavo cristatus* has given the status of our national bird. It lives in dense jungle having streams and rivers. The dance of male Peacock with its expanded train like a fan is really delightful. This fan is formed by the elongated feathers overlying the tail (Fig. 8.26G). It eats mainly the grains and vegetables. It also takes insects and small reptiles.

GREY OR SPOTTEDBILLED PELICAN (*Pelecanus philippensis*). This bird is characterised by having a large beak with an elastic skin pouch which acts as a net for capturing the fishes. Pelican lives on coastal lagoons and lakes. It is a fish-eating bird of large size (Fig. 8.26H).

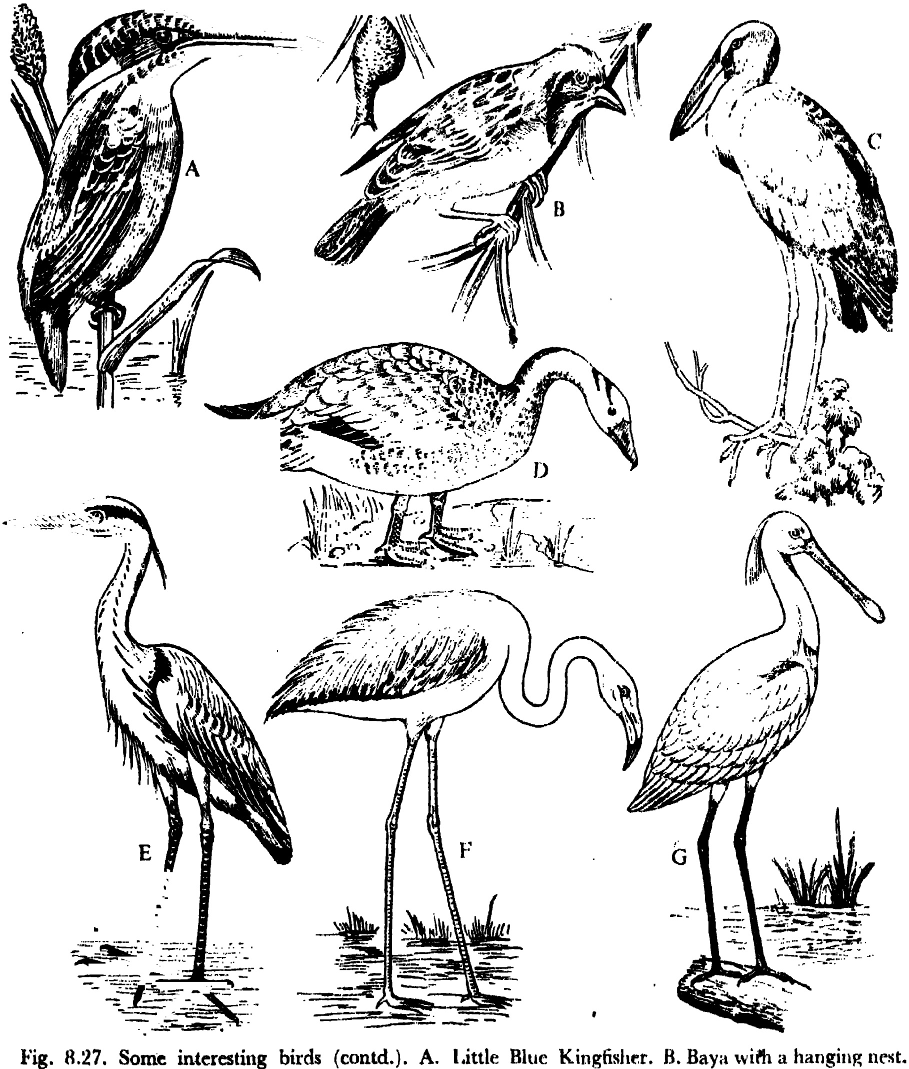


Fig. 8.27. Some interesting birds (contd.). A. Little Blue Kingfisher. B. Baya with a hanging nest. C. Openbilled Stork. D. Barheaded Goose. E. Grey Heron. F. Flamingo. G. Spoonbill.

JUNGLE BUSH QUAIL (*Perdicula asiatica*). This bird (Fig. 8.26I) lives usually in dry open forest of India. They live on grains and tender shoots. They live in groups of five to twenty.

LITTLE BLUE KINGFISHER (*Alcedo atthis*). This little bird (Fig. 8.27A) is found near the tanks, streams, lakes and the seashore and prey upon aquatic insects, tadpoles and small fishes. They produce characteristic sound during flight.

COMMON WEAVER BIRD OR BAYA (*Ploceus philippinus*). This weaver bird resembles closely the sparrow and live in flocks. They cause damage to cereal crops. These birds are well-known for their nicely woven bottle-shaped nests (Fig. 8.27B). The nests are seen hanging usually from date palms or any other trees situated usually over the water.

OPENBILLED STORK (*Anastomus oscitans*). This bird is characterised by having a peculiar beak (Fig. 8.27C) which is modified to extract the body of large snails from this shell. They have a wide distribution all over the country.

BARHEADED GOOSE (*Anser indicus*). This goose (Fig. 8.27D) has a great migratory power. During the winter months, these birds come down specially to northern India from Tibet. They live near marshy lands round canals and jheels.

GREY HERON (*Ardea cinerea*). This bird is commonly called the *Anjan* and is found standing motionless in shallow water. It has a large size and catches the prey with its elongated beak (Fig. 8.27E). It has a highly mobile and long neck. It takes fishes and frogs as the food.

FLAMINGO (*Phoenicopterus roseus*). This bird is usually found in flocks wondering in shallow jheels. It is beautifully coloured. The legs are extremely elongated (Fig. 8.27F). It lives on crustaceans, molluscs and tender vegetables which are collected by the beak modified for this purpose. During rest it usually remains standing on one leg and the head is kept tucked under the feathers of the posterior part of the body. The neck is excessively long which is highly mobile and coiled. The mandibles are curved forming box-like structure with serrated margins.

SPOONBILL (*Platalea leucorodia*). This bird is snow-white in colour and is characterised by having a peculiar spoon-like beak (Fig. 8.27G) for catching prey. It lives in jheels and banks of the river. They usually remain in flocks of 10 to 20 individuals. They have a peculiar flying posture with the neck and head outstretched.

CLASSIFICATION

Nearly nine thousand species of birds present close similarity due to aerial mode of life. Such similarity in one hand and absence of adequate fossil forms in the other, have made the classification of birds, a difficult task. The present day classification is based mostly on anatomical features, though some extinct forms are considered to establish phylogenetic relationship. The entire class is subdivided into two subclasses—Archaeornithes and Neornithes. The details of classification in outline and with characters are given below:

CLASSIFICATION IN OUTLINE

Class **Aves**

Subclass **Archaeornithes**

1. Order *Archaeopterygiformes*, e.g., *Archaeopteryx*.

Subclass **Neornithes**

Superorder ODONTOGNATHAE

1. Order *Hesperornithiformes*, e.g., *Hesperornis*.
2. Order *Icthyornithiformes*, e.g., *Icthyornis*.

Superorder PALAEOGNATHAE

1. Order *Struthioniformes*, e.g., Ostrich (*Struthio*)
2. Order *Rheiformes*, e.g., Rhea (*Rhea*)
3. Order *Casuariformes*, e.g., Emu (*Dromaeus*), Cassowary (*Casuarius*).
4. Order *Apterygiformes*, e.g., Kiwi (*Apteryx*).
5. Order *Dinornithiformes*, e.g., Moa (*Dinornis*).
6. Order *Aepyornithiformes*, e.g., Elephant-bird (*Aepyornis*).
7. Order *Tinamiformes*, e.g., Tinamus (*Eudromia*).

Superorder IMPENNAE

1. Order *Sphenisciformes*, e.g., Penguin (*Aptenodytes*, *Spheniscus*).

Superorder NEOGNATHAE

1. Order *Gaviiformes*, e.g., Divers (*Gavia*).
2. Order *Podicipitiformes*, e.g., Grebes (*Podiceps*, *Podilymbus*).
3. Order *Procellariiformes*, e.g., Albatross (*Diomedea*), Shearwater (*Puffinus*), Petrels (*Pelecanoides*).
4. Order *Pelecaniformes*, e.g., Tropic bird (*Phaethon*), Pelicans (*Pelecanus*), Gannet (*Morus*), Booby (*Sula*), Cormorant (*Phalacrocorax*), Anhinga (*Anhinga*), Frigate birds (*Fregata*).
5. Order *Ciconiiformes*, e.g., Pond-Herons (*Ardeola*), Egrets (*Egretts*), Cattle-eagret (*Bubuleus*), Bitterns (*Botaurus*), Boatbill (*Cochlearius*), Shoebill (*Balaenicceps*), Hammer-head (*Scopus*), Stork (*Ibis*, *Anastomus*), Jabiru (*Jabiru*), Adjutant Stork (*Leptoptilos*), Spoonbills (*Platalea*), Black Ibis (*Pseudibis*), Flamingo (*Phoenicopterus*).

6. Order *Anseriformes*, e.g., Screamer (*Anhima*), Magfrie Goose (*Anseranas*), Whistling ducks (*Dendrocygna*), Swan (*Cygnus*), True geese (*Anser, Branta*), Dabbling ducks (*Anas*), Pochords (*Aythya*), Perching ducks (*Cairina*), Eider ducks (*Somateria*), Diving ducks (*Mergus*) Stiff tailed ducks (*Oxyura*).
7. Order *Falconiformes*, e.g., New world vultures (*Gymnogyps, Coragyps*), Old world vultures (*Aegypius, Gyps, Neophron*), Kite (*Milvus, Haliastur*), Bearded vulture (*Gypaetus*), Eagles (*Aquila, Harpia*), Serpent eagles (*Circaetus*), Buzzards (*Buteo*) Marsh hawks (*Circus*), True hawks (*Accipiter*). Ospray (*Pandion*), Falcons (*Falco*), Secretary birds (*Sagittarius*).
8. Order *Galliformes*, e.g., Megapodes (*Leipoa*), Curassows (*Crax, Mitu*), Grouse (*Lagopus*), Black Patridge (*Francolinus*), Quail (*Coturnix*), Bob-white (*Colinus*), True Pheasants (*Phasianus. Chrysolophus*), Fowls (*Gallus*), Peafowl (*Pavo*), Guinea fowl (*Acryllium, Numida*), Turkeys (*Meleagris*), Hoatzin (*Opisthocomus*).
9. Order *Gruiformes*, e.g., Mesites (*Monias*), Hemipodes (*Turnix, Ortyxelos*), Plains-wandered (*Pedionomus*), Cranes (*Grus, Anthropoides*), Limpkin (*Aramus*), Trumpeters (*Psophia*), Rails (*Rallus*), Purple Moorhen (*Porphyrio*), Coot (*Fulica*), Sun-grebe (*Podica*), Kagu (*Rhynochetos*), Sun-bittern (*Eurypyga*), Cariamas (*Cariama*), Bustard (*Otis, Choriotis*).
10. Order *Charadriiformes*, e.g., Lilly-trollers (*Jacana, Metopidius*). Painted snipe (*Rostratula*), Oyster catchers (*Haematopus*), Sand plover (*Charadrius*), Golden plover (*Pluvialis*), Lapwings (*Vanellus*), Woodcock (*Philohela*), Common snipe (*Gallinago*), Sand pipers (*Calidris, Tringa*), Curlews (*Numenius*), Phalaropes (*Phalaropus*), Crab-plover (*Dromas*), Stone-curlew (*Burbinus*), Stone-curlew (*Burbinus*), Pratinocole (*Glareola*), Courser (*Cursorius*), Stilt (*Himantopus, Cladorhyncus*), Avocet (*Recurvirostra*), Sheathbills (*Chionis*), Skua (*Catharacta*), Jaeger (*Stercorarius*), Gull (*Larus*), Tern (*Childonias*), Skimmers (*Rynchops*), Auks (*Plautus*), Guillemot (*Uria*), Puffin (*Fratercula*).
11. Order *Diatrymiformes*, e.g., *Diatryma.*
12. Order *Columbiformes*, e.g., Sandgrouse (*Pterocles*), Green pigeon (*Treron*), Pigeon (*Columba*), Dove (*Streptopelia*).
13. Order *Psittaciformis*, e.g., Parrot (*Psittacus*). Macaw (*Ara, Psittacuba*), Cocatoo (*Kakatoe*). Parakeet (*Psittacula*), Budgerigar (*Melopsittacus*).
14. Order Cuculiformes, e.g., Cuckoo (*Cuculus*), Koel (*Eudynamys*). Anis (*Crotophaga*), Road-runner (*Geococcyx*).
15. Order *Strigiformes*, e.g., Barn owl (*Tyto*), Screech-owl (*Otus*), Eagle owl (*Bubo*), Long-eared owl (*Asio*), Pygmy owl (*Glaucidium*), Burrowing owl (*Speotyto*), Wood-owl (*Strix*), Snowy owl (*Nyctea*).
16. Order *Caprimulgiformes*, e.g., Oilbird (*Steatornis*), Frogmouth (*Podargus*), Potoo (*Nyctibius*), Nightjars (*Caprimugus*).
17. Order *Apodiformes* (or *Micropodiformes*), e.g, Swift (*Chaetura, Apus*), Swiftlets (*Collocalia*), Humming birds (*Archilochus*).
18. Order *Coliiformes*, e.g., Mouse birds (*Colius*).
19. Order *Trogoniformes*, e.g., Trogons (*Harpactes*).
20. Order *Coraciiformes*, e.g., Kingfishers (*Alcedo*), Bee-eaters (*Merops*), Cuckoo-roller, Roller (*Coracias*), Hoopoes (*Upupa*), Hornbill (*Buceros*).
21. Order *Piciformes*, e.g., Puff-bird (*Notharcus*) Barbets, Honey-guides (*Indicator*). Toucans (*Ramphastos*), Wood peckers (*Picus, Dendrocopos*).
22. Order *Passeriformes*, e.g., Broad bill (*Calyptomena*), Oven birds (*Furnarius*), Tapacutos (*Teledromas*), Pittas (*Pitta*), Asities (*Philepitta*). False sunbird (*Neoclrapanis*), Tyrant Fly-catchers (*Muscivora*), Kingbird (*Tyrannus*), Sharpbills (*Oxyrunkus*), Manakins (*Chiroxiphia*), Umbrella bird (*Cephalopterus*), Bell bird (*Chasmorhyncus*), Lyre-bird (*Menura*), Scrub-bird (*Atrichornis*), Skylark (*Alanda*), Swallow (*Hirundo*),

Pipit (*Anthus*), Wagtail (*Motacille*), Cucoo-shrike (*Coracina*), Minivet (*Pericrocotus*), Bulbuls (*Pycnonotus*), Fairy blue-birds (*Irena*), Shrive (*Lanius*), Bristle-head (*Pityriasis*), Vangashrike (*Euryceros*), Waxwing (*Bombycilla*), Palmchat (*Dulus*), Dippers (*Cinclus*), Wrens (*Troglodytes*), Mocking bird (*Minus*), Catbird (*Dumetella*), Thrasher (*Toxostoma*), Accentors (*Prunella*), Babblers (*Alcippe*), Bald-crows (*Picarthartes*), Wren-tit (*Chamaea*), Old world fly catchers (*Muscicapa*), Goldcrest (*Regulus*), True Wrablers (*Sylvia, Phylloscopus*), Tailor birds (*Orthotomus*), Wren-thrush (*Zeledonia*), Black-bird (*Turdus*), American thrush (*Hylocichla*), Nightingale (*Luscinia*), Blue-bird (*Sialia*), Tit (*Parus*), Tree-creeper (*Certhia*), Wall-creeper (*Tichodroma*), Nuthatch (*Sitta*), Australian tree-creepers (*Climacteris*), Flower-peckers (*Anaimos*), Sunbird (*Aethopyga*), Honey-eaters (*Anthornis, Moho*), Greenfinch (*Chloris*), Yellow bunting (*Emberiza*), Tanager (*Piranga*), Plush-capped finch (*Catamblyrdyncus*), Swallow-tanager (*Tersina*), Wood-warbkers (*Mniotilta*), American Finch (*Fringilla*), Crossbill (*Loxia*), Starling (*Sturnus*), Talking Mynah (*Graculа*), Golden Oriole (*Oriolus*), Drongos (*Chaetorhyncus*), Wattled crow (*Calleas*), Huia (*Heteralochia*), Saddleback (*Philestesnus*), Wood-swallow (*Artamus*), Bell-magpie (*Gymnorhina*), Piping crows (*Strepera*), Butcher-bird (*Cracticus*), Maypie (*Pica*), Nutcracker (*Nucifraga*), European jay (*Garrulus*), Blue jay (*Cyanocitta*).

CLASSIFICATION WITH CHARACTERS

Subclass **Archaeornithes**

Order *Archaeopterygiformes*. The size was slightly larger than crow and had both primary and secondary feathers. The forelimbs were modified as wings. The carpals and metacarpals were free. The hand had three clawed digits. The tail was long and provided with two lateral rows of feathers. The beak was well-developed. Thirteen pairs of conical teeth were present in the upper jaw and three pairs of similar teeth were present in the lower jaw. The skull had rounded cranium and a single occipital condyle. The zygomatic arches were fairly developed. The parietals were completely fused and inter-parietal foramen was absent. The interorbital septum was slightly developed and the orbit was provided with sclerotic ossicles. The quadrates were small. The mandible was a complex skeletal structure. The vertebrae were amphicoelous. Thoracic ribs were without uncinate processes. Caudal vertebrae were 18–20 in number and gradually become pointed at the posterior end. The pygostyle was absent. The abdominal ribs were present like *Sphenodon*. Flat sternum was devoid of keel. The pectoral girdle had rudimentary coracoid, distinct T-shaped interclavicle and narrow curved scapula. The pelvic girdle had large plate-like ilium, having distinct pre-and post-acetabular regions. The ischium had a thin foramen. The pubis was narrow, rod-like and backwardly directed. The synsacrum was absent and the sacral region consisted of six vertebrae. Humerus was short and stout. The ulna was stronger than radius. The carpals and metacarpals were free excepting the 3rd metacarpal which was fused with carpal. The tibia and fibula were separate and were of equal length. Each foot was made up of tarsometatusus and four digits. Small and opposable hallux resembled that of modern birds. These fossil birds had a long slender and smooth cerebral hemisphere. The cerebellum was small and placed behind the midbrain. In spite of this reptilian feature of brain, it is assumed that these birds were warm blooded.

The order includes two genera of fossil birds, each having a single species, *Archaeopteryx lithograpthica* and *Acheornis siemensi*. It is now assumed that both actually belong to the same genus and species and for this reason the name, *Archeopteryx* is proposed for both of them.

Subclass **Neornithes**

This subclass includes remaining fossil and living birds. In most of these birds, the short tail has a terminal pygostyle with semicircularly arranged feathers. In most members, the teeth are absent. The metacarpals and carpals unite to form carpometacarpus. Usually the claws are not present in more than two digits. Well-developed sternum bears a distinct keel or carina. The subclass includes four superorders: Odontognathae, Palaeognathae, Impennae and Neognathae.

SUPERORDER ODONTOGNATHAE

It included fossil birds which during Cretaceous period flourished to explore the resources of the sea. All these birds were provided with teeth. The brain was more like modern birds than the reptiles. It includes two orders: *Hesperornithiformes* and *Icthyornithiformes*.

Order *Hesperornithiformes*. All the members were flightless and adapted to aquatic life. The height was nearly three feet. The teeth were sharply pointed and arranged in grooves. The premaxillae were without teeth. The quadrate was single and basipterygoid process was absent. Long neck was supported by heterocoelous vertebrae. The keel was absent. The pectoral girdle was much reduced and clavicles were not united. The pelvic girdle bones were free posteriorly. They were absolutely flightless birds. The forelimb was represented only by humerus. The strongly built hindlimbs were with laterally directed feet having webbed toes. The pygostyle was absent. The examples are *Hesperornis*, *Baptornis*, *Neogaeornis*.

Order *Icthyornithiformes*. The height was nearly 20 cm. The cervical vertebrae were amphicoelous. The keel was present and the structure of shoulder girdle and forelimb resembled that of modern bird. The pygostyle was present. Examples: *Icthyornis*, *Apatornis*.

Fig. 8.28. Structure of feather of *Casuarius*.

SUPERORDER PALAEAGNATHAE

All birds (excepting *Tinamus*) are flightless and are of large size. Feathers are without hooked barbules and the barbs are free (Fig. 8.28). Tail feathers are either absent or irregularly arranged around a short pygostyle. Sternum is like a raft and keel is absent (Fig. 8.29). In the pectoral girdle, small coracoid and scapula are fully fused. The coracoscapular angle constitutes nearly two right angles and the acrocoracoid process is rudimentary or absent. Being flightless, the wings may be reduced or vestigial or absent. In the skull, large basipterygoid processes originate from the basisphenoid. The palatines are separated by a broad vomer and are not in contact with the cranium. A single or incompletely divided cavity acts as the articulating surface for quadrate. The sutures between the skull bones are secondarily retained. Erectile penis in male and clitoris in female are present. Extinct palaeognathae were larger in size than living forms. The superorder includes five living orders: *Struthioniformes*, *Rheiformes*, *Casuariiformes*, *Apterygiformes*, *Tinamiformes* and two extinct orders: *Dinornithiformes* and *Aepyornithiformes*.

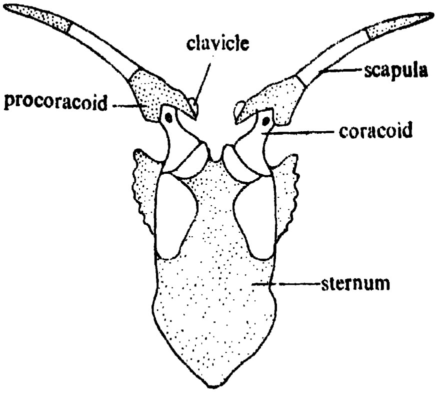


Fig. 8.29. Sternum and pectoral girdle *Casuarius*.

Order *Struthioniformes*. These birds are distributed in Africa and Arabia. The height is nearly 240 cm and weight is 345 pounds. It is considered as the largest living bird. Feathers are without aftershaft. Wings are small and usually kept folded during running, but may be expanded to work as a brake or steering. Two wing fingers are clawed. and used for defence. Tail feathers are replaced by long tail coverts. Hindlimbs are strongly built and not covered by feathers. Only the 3rd and 4th toes are present in the hindlimb. Neck is long and not covered by feathers. Head is small and flat. The two beaks are more or less round and enclose a broad space. Prominent eyes have lashes on the upper eyelid. The order includes a single species, *Struthio camelo* which is well adapted to live in desert condition.

Order *Rheiformes*. These birds are found in South America. These running birds live in a group. Food varies from vegetable products to insects. The height of a male bird is about 165 cm. Neck is incompletely feathered. Each hindlimb has three clawed toes which are webbed at the base. During breeding season, the males select and seggregate with 3–7 females to form a harem. The nest is dug by the male and all the females lay eggs in the same nest. Nearly fifty eggs are laid in a season and the male incubates them. Freshly laid eggs are lemon yellow in colour and hatching requires forty days' incubation. It includes two species—*Rhea americana* (South American form) and *Pteronemia pennata* (Darnius Rhea).

Order *Casuariiformes*. The birds enjoy distribution at Australia, New Guinea and East India. The order includes two families—Dromaiidae and Casuariidae. The Dromaiidae includes common Emu (*Dromaeus novaehollandiae*). It attains the height of 180 cm. Neck has incomplete lining of feathers. Each hindlimb is provided with three toes of which the inner one is built up as a defensive structure. The colouration in both the sexes is deep brown. All the feathers have aftershafts of equal length to the main quill. Emu is monogamous. The male digs the nest and sits over the first brood of eggs. The female sits over the second brood. Number of eggs may be fifteen or more and the eggs are green in colour. The incubation period is 60 days. The family Casuariidae includes Cassowary (*Casuarius casuarius*) which lives a solitary life in the dense tropical forests of Australia, New Guinea and East India. Several species of Cassowary are available and their height may be 135 cm. Feathers look like furs. Stiff and rod-like wing feathers hang over the side of the body. The head and neck are partly covered by feathers and have bright colouration. In some forms the neck bears identically coloured wattles. In all forms, the head has a horny helmet to help in advancing through dense jungle. The hindlimbs are similarly built as in Emu.

Order *Apterygiformes*. The members are distributed in New Zealand. The size is like a hen. They are nocturnal and eat insects, worms and vegetable matters. The feathers look like hairs. The eyes are small. The beaks are long and pointed. The nostrils are present on the tip of the beak. These birds can run speedily. Each hindlimb has four clawed toes, which may also be used for defence. The wings are much reduced and the tail is absent. Only one egg is laid at a time and it is white in colour. The order includes a single family Apterygidae having three species, *Apteryx australis* (common Brown Kiwi), *Apteryx hoasti* (greater spotted Kiwi) and *Apterynx oweni* (little spotted Kiwi).

Order *Dinornithiformes*. It included fossil running birds of New Zealand which are called Moas (two families having twenty species). The size varied widely and some attained the height of 300 cm. In most Moas, wings, pectoral girdles and keel were absent. Probably the Moas were vegetarian and possessed short beaks. The feathers were without barbicels.

Order *Aepyornithiformes*. These large, extinct running birds of Madagascar are commonly called 'Elephant birds' (*Aepyornis*). Some attained the height of 300 cm. and their eggs measured 30·5 cm. × 24·5 cm. The wings were small. The hindlimbs having four toes were strongly built.

Order *Tinamiformes*. The birds under this order are found in Southern Mexico, Central and South America. The size varies from that of Quail to a Partridge. The tail is absent. When chased, these birds run and can fly a short distance. The keel is present, but the appearance of palate is palaeognathous. These vegetarian birds do not perch and usually use their cryptic colouration for protection. The eggs have peculiar shining white shell and are incubated by the males. The order includes a single family Tinamidae having more than fifty species. The most common species are *Crypturellus variegatus* (Variegated Tinamon) and *Eudromea elegans* (Crested Tinamon).

Superorder IMPENNAE

This superorder includes birds which originated from ancestors which had wings to be used both for flight and swimming. Gradually the power of flight was lost and body became heavy. Such a change converted the wings into effecting swimming paddles. It includes only one order Sphenisciformes.

Order *Sphenisciformes*. Penguins, members of this order, are distributed in Southern part of South America, South Africa, Australia, Anatarctic regions and Galapago islands. The body is perfectly suited for diving and swimming. For this purpose, the body is streamlined. The skeleton is solid and air-sacs are absent. The integument is provided with thick fatty insulating layer and feathers form a compact outer covering. The wings are without feathers and are supported by flat and fused skeletons which are articulated only at the joint of pectoral girdle. The hindlimbs are modified for swimming. The metatarsals are incompletely fused and toes are webbed. But these limbs are used for walking on the shore. Food includes fishes, custaceans and squids. These are gregarious birds and nesting results in a large colony. Monogamous in nature and one egg is laid at a time. Male takes considerable part in incubating and rearing up of the young. The well known species are *Aptenodytes forsteri* (Emperor penguin), *Aptenodytes patagonica* (King penguin), *Pygoscelis adeliae* (Adelie penguin), *Eudyptes crystatus* (Rockhopper penguin), *Eudyptula minor* (Fairy penguin), *Eudyptula albosignata* (White flippered penguin) and *Spheniscus demersus* (Jackars penguin).

Superorder NEOGNATHAE

In this superorder, the birds have jaw arrangement completely different from Palaegnathae. Here, the slender vomer separates the palatines imperfectly. The palatines are protruded posteriorly to be in contact with the base of the cranium and remain movably articulated with small pterygoids. This type of jaw arrangement is known as neognathous condition. Majority of the neognathous birds are able to fly and most of them possess keel or carina in the sternum. It includes twenty two orders, of which one order is entirely extinct.

Order *Gaviiformes*. The birds are distributed in North America, Europe and Arctic region. Fully adapted for aquatic life and are expert in swimming and diving. The neck is long. The legs are posteriorly placed and completely encased within skin. The digits are webbed. In water only legs are used for swimming. The bones are not fully pneumatic. The wings are short and it flies very rarely. But once in air they can fly effectively. During summer these birds stay in fresh water but in winter shift to salt waters. The brightly coloured body has similar pattern in both the sexes except during breeding season. All the wing feathers moult together; for this season these birds pass through a flightless period. Due to its inability to move on land, these birds are helpless on land. Eggs are laid in nests among reeds. The well known examples are *Gavia stellata* (Red-throated Diver Loon), *Gavia immer* (Great Northern Diver or Common Loon) and *Gavia adacusi* (White billed diver or Yellow billed Loon).

Order *Podicopitiformes*. The distribution is cosmopolitan. They are aquatic and built up nests in floating vegetation. They usually live in fresh water. The legs are placed posteriorly. Only three front toes are webbed by lobed fringing membranes. Reduced tail has degenerated tail feathers. The largest genus is *Podiceps* (Grebe or Dabelien) and other genera are *Aechmophorus* (Large western Grebe), *Podilymbus* (Pied-billed Grebe) and *Centropelara* (Short-winged Grebe).

Order *Procellariiformes*. All the members are marine and come to land only during breeding season and built up nest in holes or crevices in the ground. Hooked bill lies encased within horny plates. Nostrils are tubular and have well developed olfactory receptors. The wings are long in comparison to the size of the body. Only one egg is laid at a time. It includes four families and the well known examples are Albatrosses (*Diomedea*, *Phoebetria*), Shear water (*Puffinus*), Fulmars (*Fulmar*), Cape Pigeon (*Daption*), Prions (*Pachyptila*), Storm petrels (*Oceanites*), Diving petrels (*Pelecanoides*).

Order *Pelecaniformes*. The distribution is cosmopolitan. All are aquatic and fish-eaters. Long beaks have wide gap. Size is usually large and body is adapted for diving. Hindlimb has four digits which are completely webbed. They make nest in a colony and feed the nestlings by regurgitated food. It includes seven families and well known examples are: Tropic birds (*Phaethon*), Pelicans (*Pelecanus*), Gannets (*Morus*), Boobies (*Sula*), Cormorants (*Phalacrocorax*), Darter or Anhinga (*Anhinga*) and Frigate birds (*Fregata*).

Order *Ciconiiformes*. The distribution is cosmopolitan. All the birds have long naked legs and long bill. The legs are adapted for walking on marshes and mudflats. Four toes are present in each foot, which only in one family (Phaenicopteridae) are webbed. All these birds can fly speedily. The pattern of beak varies but in all, the beak has sharp-cutting edges. Food capture involves careful observation and speedy striking by the action of mobile neck and beak. It includes six families and well known examples are Herons (*Ardea*), *Butorides*, *Hydranassa*), Egrets (*Egretta*), Bitern (*Botaurus*, *Ixobrychus*), Night herons (*Gorsachius*, *Nycticorax*, *Nyctarassa*), Boatbill (*Cochlearius*), Shoebill (*Balaeniceps*), Hammerhead (*Scopus*), Storks (*Ciconia*, *Mycteria*, *Euxenura*, *Leptoptilus*), Jabirus (*Jabiru*), Spoonbills (*Platalea*, *Ajaia*), Ibis (*Threskiornis*, *Eudocimus*, *Plegadis*) and Flamingo (*Phoenicopterus*)

Order *Anseriformes*. The distribution is cosmopolitan. Most birds are aquatic but are also capable of flying well. Feeding habit varies from vegetarian to fish eater. Beak is provided with special tactile organ to help in selecting food. All the toes are webbed. It includes two families and common examples are Screamers (*Anhima*), Magfric goose (*Anseras*), Whistling ducks (*Dendrocygna*). Swans (*Coscoroba*, *Cygnus*), Dabling ducks (*Anas*), Pochard (*Aythya*, *Netta*, *Nyroca*), Goose (*Anser*, *Branta*), Shelducks (*Tadorna*, *Casarca*, *Alopochen*), Perching ducks (*Cairina*, *Dendronessa*), Eider ducks (*Somateria*, *Polysticta*), Diving ducks (*Mergus*, *Lophodytes*) and Stiff tailed ducks (*Oxyura*).

Order *Falconiformes*. The distribution is widespread throughout the world excepting Antartica. It includes the birds which are adapted for day-time predatory life. Body is strongly built with prominent hook-like beak with cutting edge and the feet are provided with curved, pointed claws in the digits. The lower beak remains enclosed by the upper beak. The base of the upper beak bears wart-like variedly coloured protuberance called cere which is pierced by nostrils. Feathers are stiff and cover the legs excepting the digits. Eyes are laterally placed but power of vision is extremely sharp. They lead solitary life or in pairs. Most birds are monogamous but before mating, fighting and courtship display occur. Eggs are limited in number and usually one. The incubation is done by female only. The male feeds the female during the act. Nests are made on greeb heights and in inaccessible places. For a considerable period, the nestlings remain dependent upon the parents. It includes four families and the well known examples are vultures (*Vultur*, *Gymnogyphs*, *Sarcoramphus*, *Aegypices*, *Gyps*), Kites (*Mileres*, *Haliastur*, *Ictinia*), Eagles (*Aquila*, *Hieraetus*, *Harpia*, *Haliaetus*), Buzards (*Buteo*), Harriers (*Circus*), True Hawks (*Accipiter*), Ospreys (*Pandion*), Falcons (*Falco*) and Secretory bird (*Sagittarius*).

Order *Galliformes*. The distribution is cosmopolitan. Various types of birds are included in this order, the largest one is 225 cm. in length and smallest size is 12.5 cm. in length. The head is small but body is compact. The legs are massive, clawed and used for scratching the soil to search food. Three toes are anteriorly directed and one is posteriorly directed. All the birds are terrestrial and usually nonmigratory in habit. In most members, the wings are short and round. For this reason these birds cannot fly well, but all are good runners. The beaks are strongly built and arched, most suitable for picking up grains and seeds. Sexual dimorphism is noted. Males are aggressive polygamous and do not take part in nest building and maintenance of youngs. It includes seven families and well known examples are Megapodes (*Leipoa*), Curassows (*Crax*, *Mitu*, *Oreophasis*), Grouse (*Lagopus*, *Tetrao*, *Lyrurus*), Partridges (*Perdix*, *Alectoris*), Quail (*Coturnix*), Bobwhite (*Colinus*), Francolins (*Francolinus*), True Pleasants (*Phasianus*, *Chrysolophus*, *Lophura*, *Gallus*, *Argusianus*, *Pavo*), Guinea fowl (*Acryllium*, *Namida*), Turkeys (*Melagris*) and Hoatzins (*Opisthocomus*).

Order *Gruiformes*. The distribution is cosmopolitan excepting polar region. The members belonging to this order are primarily aquatic but some have settled in grass-land and some have become reed-dwellers. They feed usually on vegetable matters. The toes are not webbed. Nests are built on the ground. This order includes as many as ten families and well known examples are Merites (*Monias*), Button-quail (*Turnix*), Plains wanderer (*Pedionomus*), Cranes (*Grus*, *Babarica*), Limpkin (*Aramus*), Trumpeters (*Prophia*), Rails (*Rallus*), Crakes (*Crex*), Moorhens (*Gallinula*), Coot (*Fulica*), Sungrebe (*Heliopais*, *Heliornis*, *Podica*), Kagu (*Rhynochetos*), Sunbittern (*Eurypyga*), Cariamas (*Cariama*) and Bustards (*Otis*, *Choriclis*, *Lissotis*).

Order *Diatrymiformes*. These birds were distributed in Europe and North America. It included the extinct birds which attained the height of 210 cm. These terrestrial birds were flightless and adapted for cursorial life. The feet had four toes, three anteriorly directed and one at the opposite side but raised above the ground. The beaks were strongly built. The well known example is *Diatryma steini* which was found from North American ocean bed and related to birds belonging to the Gruiformes, i.e., Cranes, bitterus, etc.

Order *Charadriiformes*. These birds enjoy universal distribution excepting polar regions. This order includes variety of forms which live near water, some live on shore, some on aquatic leaves and some have become aquatic. The feet show various modifications according to the habitats. It includes sixteen families and well known examples are Jacanas (*Jacana*), Painted snipe (*Rostratula*, *Nycticryphes*), Oyster catchers (*Haematopus*), True plovers (*Charadrius*, *Plyvialis*), Lapwings (*Vanellus*), Woodcock (*Scolopax*), Snipes (*Gallinago*, *Lymnocryptes*), Sandpipers (*Calidris*, *Philomachus*, *Tringa*), Curbus (*Numenius*), Stilt (*Himantopus*, *Cladorhyncus*), Avocet (*Recurvirostra*), Phalcropes (*Phelaropus*, *Steganopus*), Crab-plover (*Dromas*), Stone-curbus (*Burhinus*), Pratincoles (*Glareola*), Courser (*Cursorius*), Sheathbills (*Chionis*), Skuas (*Stercorarius*, *Catharacta*), Gulls (*Larus*), Terns (*Sterna*, *Anous*), Skimmers (*Rynchops*), Dovekie (*Plautus*), Guillemot (*Uria*), Puffin (*Fratercula*) and Razorbill (*Alca*).

Order *Columbiformes*. The birds under the order are present throughout the world excepting polar regions. All the members are adapted to land life. The size varies from that of a swan to a pigeon. The head and neck are small and the compact body is supported by small legs. Each foot has four toes, of which three are forwardly directed and one is backwardly directed. All the toes lie in the same plane and have small straight claws. The wings are long pointed, and enable the bird to make sustained flight at great speed. In pigeons and doves, the basal part of the beak has a covering of soft skin which bears longitudinal slit-like nostrils. Both the sexes are alike. Monogamous but lives in a group. Male takes part in nest building and rearing of youngs. Youngs are helpless and are nourished by 'pigeon's milk' produced by both the sexes during breeding season. Number of eggs range from two to three. It includes three families, of which one is extinct (Raphidae). The extinct family includes bird like Dodo. The living birds which are included under this order are Sandgrouse (*Pterocles*, *Syrrhypta*), Rock pigeon (*Columba livia*), Passenger pigeon (*Ectopistes*), Turtle dove (*Streptopelia*), Nicober pigeon (*Cabonas*), Parrot pigeons (*Treron*), Crowned pigeons (*Coura*) and Tooth billed pigeon (*Didunculus*).

Order *Psittaciformes*. They are distributed in the tropical region but concentrate in Australia, New Zealand and South America. All the members are specially adapted for arboreal life and can also climb. The beaks are used to help in climbing and feet are also used as 'hand' to hold the food. The upper jaw is movably articulated with the cranium. The first and fourth digits are backwardly directed, thus provide better aid to grasp the branch. The feathers are usually brilliantly coloured. They live in flocks but are strictly monogamous. The nest is usually built in the hollows of the tree. Youngs are nourished till the attainment of maturity. Excepting a few parrots (*Geopsittacus*) all are diurnal. The order has a single family and the well known forms are Macaw (*Ara*), Amazons (*Amazona*), Cockatoo (*Kakatoe*), Parrot (*Psittacus*), Parakett (*Conuropsis*), Budgerigar (*Melopsittacus*), Love birds (*Agapornis*, *Prittacula*) and Kea (*Nestor*).

Order *Cuculiformes*. These birds are distributed in the tropical and subtropical regions but concentrated in temperate regions. In all the members, the pattern of digits in the leg are same as that of parrots, but these birds cannot climb. The wings are long and enable these birds to take sustained flight. It includes two families and well known examples are Turacos, Cuckoos (*Cuculus*, *Chalecites*) and Road runner (*Geococcyx*).

Order *Strigiformes*. They enjoy universal distribution. All these birds are nocturnal and live upon hunting small animals (e.g., rodents). Like diurnal birds of prey, beaks and claws are strongly built. The construction of wing feathers is such that they produce noiseless flight. Detail examination reveals that outer vane of each outermost wing feather is narrow and constitutes a loose fringe. Such construction, at the time of wing flapping, separates the fast moving and stationary air by a thin slower moving cushion of air. The contour feathers are loosely arranged and extend up to the digits. Eyes are large and round. Both the eyes are directed frontally. With the help of neck, it can move its eyes up to 180°. The retina contains only rod cells and are adapted only to feel low intensity of light. The ear openings are placed on the lateral sides of the head and can be closed at will. These birds depend more on its auditory function during hunting than vision. It includes two families and well known examples are common Barn owl (*Tyto*), Eagle owl (*Bubo*), Long-eared owl (*Asio*), Scops owl (*Otus*), Little owl (*Athene*), Pygmy owl (*Glaucidium*), Burrowing owl (*Speotyto*), Wood owl (*Strix*) and Snowy owl (*Nyctea*).

Order *Caprimulgiformes*. The distribution is tropical, subtropical and temperate zones. It included nocturnal birds which hunt insects and other small animals during twilight. The opening of mouth is broad and the lining has specialised sensory receptors. The arrangement of feathers are like owl and they are silient-fliers. The colouration is protective and helps the bird to conceal easily. It includes five families and well known examples are Frogmouths (*Podargus*), Wood-nightjars (*Nyctibius*), and Nightjars (*Caprimulgus*, *Nyctidramus*, *Chordeiles*).

Order *Apodiformes*. The members of this order are called the swifts and humming birds. The swifts are seen throughout the world but humming birds are seen only in Central America. These birds have short legs and long wings. These can fly very swiftly. They are usually insect feeders, but humming birds take nectar. In swifts the mouth is broad and eyes are large. In humming birds, the tongue is protrusible and wings can perform hovering movement. The order includes three families which include well known examples like Swifts (*Apus*, *Chaetura*), Crested swifts (*Cypsiurus*) and Humming birds (*Archilochus*, *Selasphorous*, *Patagona*, *Meliisuga*, *Loddigeria*).

Order *Coliiformes*. They are restricted in Southern Africa. The size is small (27.5 to 35.0 cm.). The legs are short and the digits have sharp curved claws. The hallux or outer toe is reversible and can be brought forward to help in creeping on trees. Around the nostrils the base of the bill is fleshy. The feathers are soft and look like hairs. Usually a crest is present on the head. They always remain in a group of twenty or thirty. It includes a single family Coliidae and the example is mouse-bird (*Colius*).

Order *Trogoniformes*. They are distributed in Asia, Africa and tropical parts of America. The foot has peculiar arrangement of toes, the first and second are directed backwards and the third and fourth are anteriorly directed. They lead a solitary life in dense forest and capture insects in the early morning and during twilight. The feathers are soft and flight is noiseless. Small and strongly built bill has bristle-like feathers in its base. The tip of the beak is hook-like and in some cases it is denticulated. Long and stiff tail supports against vertical surface at the time of digging. It includes a single family Tragonidae and well-known examples are Tragons (*Herpactes*, *Haplodermes*, *Calures*) and Quatjal (*Pharomechrus*).

Order *Coraciiformes*. The distribution is cosmopolitan, especially in the tropical climates. The members belonging to this group exhibit varied structures. In most members the wings and legs are short. The beak is long. The body is brightly coloured and nests are built up as holes in the trees. In some forms, a few anteriorly directed toes are fused (Syndactylous) and in others one of the toes is reversed (Zygodactylous). It includes nine families and well-known examples are Kingfishers (*Alcedo*, *Ispidina*, *Dacelo*, *Tanysiptera*, *Chloroceryle*, *Ceryle*), Todies, Motmots, Bee-eaters (*Merops*), Cuckoo-roller, Rollars (*Coracis*), Ground rollers, Hoopoes (*Upupa*), Wood Hoopers and Hornbills (*Buceros*, *Anthracoceros*).

Order *Piciformes*. They are distributed throughout the world excepting Australia and polar regions. The most important character is the occurrence of zygodactylous feet, second and third toes are directed forward and the first and fourth are pointed backwards. Usually insectivorous but some forms may be vegetarian. Most members nest is holes but one family (Indicatoridae) lays eggs in the nests of other birds. This order includes six families and the well known examples are Jucamars, Puff birds (*Notharcus*), Barbets (*Megalaima*), Honey guide (*Indicator*), Toucaus (*Ramphastos*) and Woodpeckers (*Picus*), Dendrocopos, (*Sphyrapicus*, *Melanerpes*, *Jynx*).

Order *Passeriformes*. They enjoy world wide distribution. This is the largest order, which includes 5,100 known species. All are collectively known as Perching birds or Passerines. Adapted to various habitats, they practice various modes of feeding. All are adapted to land life and in all the four digits are present at the same level. Nestlings are hatched, only with a few feather tracts and are helpless at the beginning. This order is subdivided into four suborders: Eurylaemi, Tyranni, Menurae and Oscines. All these suborders include sixty-five families. Familiar examples are Broadbills (*Calyptomena, Eurylaimus*), Woodhewer (*Xiphorhynchus*), Ovenbirds (*Furnarius*), Tapaculos (*Teledromas*), Pittas (*Pitta*), Asities (*Philepitta*), New Zealand wrens (*Xenicus, Acanthisitta*), Flycatchers (*Muscivora, Tyrannus, Myiarchus, Sayornis, Empidonax, Contopus*), Sharpbills (*Oxyruncus*), Manakins (*Chiroxiphia*), Chatterers (*Cephalopterus, Chasmorhyncus*), Lyrebirds (*Menura*), Scrub birds (*Atrichornis*), Larks (*Alauda, Lullula, Calandrella, Galerida*), Swallows (*Hirundo, Petrochelidon, Riparia, Delichon, Cecropis*), Pipits (*Anthus*), Wagtails (*Motacilla*), Cuckoo-shrikes (*Coracina, Campephaga*), Minivet (*Pericrocotus*), Bulbul (*Pycnonotus*), Fairy bluebirds (*Irena*), Iora (*Aegithina*), Leaf-bird (*Chloropsis*), Shrikes (*Lanius, Prionops*), Vanga-shrikes (*Euryceros*), Waxwings (*Bombycilla, Hypocolius*), Palm chat (*Dulus*), Dipper (*Cinclus*), Wrens (*Troglodytes*), Mocking birds (*Mimus*), Cat birds (*Dumetella*), Thrashers (*Texestoma*), Babblers (*Alcippe, Chrysomma, Rhinomyias, Turdoides, Eupetes*), Bald Crows (*Picarthartes*), Wren-tit (*Chamaea*), Old world fly catchers (*Muscicapa, Terpsiphone, Rhipidura*), True warbbers (*Sylvia, Phylloscopus*), Wren-thrush (*Zeledonia*), Black bird (*Turdus*), Rock-thrush (*Monticola*), Nightingale (*Luscinia*), Shama (*Kittacincla*), Forktail (*Exicurus*), Wheatear (*Oenanthe*), Titmice (*Parus*), Tree-creeper (*Certhia*), Wall-creeper (*Tichodroma*), Nutchatch (*Sitta, Hypositta*), Australian tree-creeper (*Climacteris*), Flower peckers (*Anaimos, Dicaeum*), Sunbirds (*Aethopyga, Nectarinia*), White-eyes (*Zosterops*), Honey-eaters (*Prosthemadera, Moho*), Buntings (*Emberiza*), Cardinal (*Richmondena*), Tanagers (*Piranga*), Plus-capped finch (*Catamblyrynchus*), Swallow-tanager (*Tersina*), Wood-warbbers (*Mniotilta, Dendroica*), Vireos (*Vireo*), American Black bird (*Quiscalas, Euphagas*), Orioles (*Icterus*), Meadow-lark (*Starnella*), Cowbird (*Molothrus*), Finches (*Fringilla, Coccothraustes, Loxia, Carduelis*), House sparrow (*Passer*), Weaver birds (*Ploceus*), Starlings (*Sturnus*), Old world orioles (*Oriolus*), Drongo (*Chaetorhyncus, Dicrurus*), Wattled crow (*Calleas*), Huia (*Heteralocha*), Magpie-larks (*Grallina, Struthidea, Corcorax*), Wood-swallows (*Artamus*), Bell-magpie (*Gymnorhina*), Piping crows (*Strepera*), Butcher birds (*Cracticus*), Birds of Paradise (*Paradisea*), Crow (*Corvus*) and Magpie (*Pica, Cissa*).

Comparison between Ratites and Carinates

The flightless birds or 'ratites' are included under the Superorder Palaeognathae. These birds are characterised by having raft-like keelless sternum, palaeognathous (large and broad vomer separates the palatines which do not come into contact with cranium) type of palate and curly feathers. They differ from the remaining modern birds (constituting the superorder Neognathae) having neognathous jaw condition (small vomer with rigid palato-cranial articulation) and keeled sternum by many points. The differences are summarised in Table Chordata 14.

TABLE CHORDATA-14

Points	Ratites (Palaeognathae)	Carinates (Neognathae)
1. Distribution ..	Discontinuous. Except Ostrich, they are confined to southern continents and islands.	Cosmopolitan.
2. Habitat ..	Terrestrial—usually living in desert.	In all spheres.
3. Size	Usually large.	Variable—but smaller in size.
4. Tail	Functionless.	Functional, actively helps in steering during flight.
5. Feathers ..	Devoid of hooks and hooklets. The barbs are free.	Barbs are united by hooks and hooklets, i.e., the barbs are united.

TABLE CHORDATA–14 (*contd.*

Points	Ratites (Palaeognathae)	Carinates (Neognathae)
6. After shaft	Usually well-developed.	Usually ill-developed except Heron.
7. Rectices	Absent or irregularly arranged. These are never fan-shaped.	Present, regularly arranged round the uropodium. These are fan-shaped.
8. Down feathers	Absent.	Present.
9. Pterylosis	The apteria is usually absent in adult, but distinct in youngs.	Apteria is well-marked.
10. Wings ..	Reduced in size, may be vestigial or absent.	Well-developed and constitute the principal organs for flight.
11. Uropygial gland	Absent except Kiwi.	Present.
12. Rhamphotheca (horny sheath to the beak).	Compound, composed of several separate pieces.	Usually undivided, may be compound in Albatross.
13. Nature of skull	Large and strongly built.	Small, light and fragile.
14. Type of skull ..	Dromaoegnathous.	Never dromaeognathous, may be schizognathous or aegithognathous or desmognathous.
15. Sutures of skull ..	Persistent.	Absent in adult.
16. Quadrate ..	Y-shaped bone, articulates with the squamosal by a single or partly divided facet.	Never Y-shaped, articulates by two facets.
17. Vomer ..	Large, broad and separates the palatines.	Small, narrow and may be truncated.
18. Palatines ..	Do not articulate with the rostrum.	Converge together behind and movably attached to vomer by a cup-and-ball joint.
19. Maxillo-palatine pro-	Small, do not articulate with one another.	Unite with one another to form large secondary palate.
20. Basipterygoid process	Large and developed from the basisphenoid.	May be absent, if present, hangs from the base of the rostrum.
21. Sacral vertebrae ..	Not firmly ankylosed.	Most of them are firmly ankylosed.
22. Pygostyle ..	Undeveloped.	Well-developed.
23. Sternum ..	Plate-like without keel. No trace of carinal ossification in young.	Well-developed with a prominent well ossified midventral keel or carina.
24. Scapula ..	Plate-like.	Sabre-shaped.
25. Coracoid ..	Plate-like.	Pillar-like.
26. Coracoid and scapula	Comparatively smaller and completely ankylosed.	Both are well-developed and not ankylosed.
27. Coraco-scapular angle	Approaches two right (obtuse) angles.	Less than 90° (acute), exceeds 90° in Albatross.
28. Furcula ..	Absent.	Present and well-developed.
29. Acromion and Acrocoracoid processes	Absent or vestigial.	Well-developed.

TABLE CHORDATA–14 (*contd.*)

Points	Ratites (Palaeognathae)	Carinates (Neognathae)
30. Ilium and Ischium ..	Loose and not fused posteriorly.	Completely fused posteriorly.
31. Pelvic symphysis ..	Pubic symphysis is present in Ostrich and ischiatic symphysis is found in Rhea.	Absent.
32. Limb-bones ..	Not much pneumatic.	Highly pneumatic.
33. Digits in forelimbs ..	Usually three digits are present, two with claws.	Usually three digits are found and claws are absent in adult.
34. Hindlimbs	Usually elongated — adapted to cursorial life.	Usually adapted for cursorial/arboreal/aquatic life.
35. Tongue ..	Usually small.	Prominent and pointed at the tip.
36. Caecum ..	Very large.	Usually small.
37. Flight muscles ..	Completely reduced.	Well-developed. May be slightly reduced in flightless forms.
38. Syrinx ..	Absent except Rhea.	Present.
39. Air-sacs	Ill-developed or absent.	Highly developed and play important role.
40. R.B.C.	Smaller in size.	Larger in size.
41. Ovary ..	Both the ovaries may be present.	Usually right ovary is absent.
42. Penis ..	Present.	Absent except duck.
43. Egg-shell	Thick and hard.	Thin and fragile.
44. Pore-canal	Branched.	Unbranched.
45. Youngs ..	Usually precocial, i.e., independent.	Altricial, i.e., dependent and helpless.

Opinions differ as regards the phylogenetic relationship between the 'ratites' and 'carinates'. It is claimed that the ratites are primitive than carinates. This contention is untenable today because the condition of the cerebellum indicates their emergence from volant ancestors and many carinates have been recorded to have lost many carinate features especially the conversion from keeled to raft-like sternum due to their loss of flight. Many workers, particularly de Beer suggested that the so-called primitive features of the ratites, *viz.*, the condition of the feathers with free barbs without hooks, arrangement of palate bones, retention of sutures in the skull are essentially neotenous characters and not primitive as advocated by earlier workers. Many neognathous birds pass through palaeognathous condition during development and the latter is possibly an arrested development of neognathous condition as suggested by McDowell. The above evidences suggest that the ratites have been evolved from flying ancestors. They do not form a natural group, but represent a heterogeneous assemblage of several evolutionary lines.

GENERAL NOTES ON BIRDS

One of the most characteristic features of avian life is the ability of flight in most of the cases. They are noted for their great uniformity of structures. All of them have spindle-shaped stream-lined body to offer least possible resistance during forward progression. The power of flight has caused greatest changes in their biological organisation. Most of them are essentially double adapted forms, the anterior parts of the body become modified for flight while the posterior extremities have changed for movement on land. All birds are bipedal forms having well-developed legs. The pelvis and the posterior portion of the vertebral column become greatly modified for this purpose. The union between the pelvis and the vertebral column is very strong and extensive. The fusion of the posterior vertebrae to form a rigid bony piece added additional mechanical strength. The neck is long, mobile and supports a rounded head with a projecting characteristic beak.

Although the basic organisation is fairly uniform, different forms of birds exhibit a great variety of specialised features which have enabled them to adapt themselves in numerous habitats. Besides differences in body form, behaviour, power of flight, feeding habits, modifications of the beak, feet, wings and many other parts have been encountered. These modifications are manifestations of adaptation in varying environment.

HABIT AND HABITAT

Birds enjoy a wide range of distribution and occupy all continents, the seas and islands, the Arctic and Antartic regions and extend even above 20,000 feet from sea level to the highest peak of mountain range. In spite of their ability to fly in air, the birds conform to the principles of animal distribution, i.e., each species of bird occupies a definite geographical range and enjoys particular habitat. Some forms like albatrosses live on open seas except nestlings; gulls, murres and auks live near seacoast; woodpecker, creepers and nuthatchers make the trees their homes. Birds are also noted for their diversities in food habits and locomotory methods. Many birds capture insects as food while forms like hawks sour for hunting. Most of the tree-dwelling birds use the crevices or holes of the trees as the nests, while others prepare nests for nesting and rest. Insect eating birds and birds of prey usually live and hunt alone; robins, quail and juncos live in flocks, but seggregate in pairs during breeding season; and birds like pigeons, blackbirds, seafowls always remain in companies.

SKIN AND COLOURATION

The skin of birds is thin, loose and devoid of any skin gland. The uropygial gland is the only skin gland in birds which may be lacking in some cases. This gland is well-formed in aquatic birds. The uropygial gland is a bilobular structure situated on the dorsal side of the uropygium. The function of this gland is not properly known. It has been suggested that the secretion of this gland makes the feathers waterproof or produces characteristic recognition scent or produces ergosterol which is transformed into vitamin D by exposure to sunlight. Nerve endings are abundantly present in the skin.

The feathers and the scales are the major exoskeletal structures of the birds. The beak and the claws are also specialised scale-like structures. The keratin-producing capacities of skin are mostly devoted to the production of feathers—the most important exoskeletal structures in avian morphology.

Feathers. In modern birds, the feathers cover the body. The feathers play the role of heat regulation, help in flight and exhibit protective colouration and sexual display. The feathers, except penguins and ratites, are arranged in definite feather-tracts (pterylae) separated by featherless areas (apteria). Many birds have their body covered by temporary feathers (*nestling-down*) at the time of hatching. The nestling-down feathers assume various forms and are replaced by permanent feathers. In some cases, the nestling-down feathers may be present in adult. There are various types of permanent feathers which have already been discussed while describing the feathers of *Columba*.

The arrangement and types of feather are important in classification. In ratites, the apteria are distinct in youngs which are obliterated in adult when the body has a uniform covering of feathers. The barbs of the feathers are free, i.e., the barbs lack hooking apparatus. The remiges and rectrices are well-formed in flying forms. The rectrices vary greatly. These are almost absent in birds living near to the ground, being well-formed in fast-moving forms. The rectrices help in steering during progression. In penguins the remiges are degenerated, because the wings have transformed into paddles for swimming.

The feathers are regularly shed at intervals, either at a certain stage in the life-cycle or seasonally. New feathers are produced from the old papillae. Most of the birds moult annually after the breeding season, while others moult a second time during the year.

Colourations in birds. Birds are specially noted for the exhibition of different vivid colour patterns. These colour patterns form the basis of the avian social life.

The colours are used for protection, as the signs of recognition and sexual stimulation.

The colour patterns vary greatly in birds according to the habits. Cryptic (concealing) colouration is very common which renders the birds less visible. This is aided by counter-shading (the upper side with stronger lighting becomes darker than the lower side which is whitish). In most birds the colouration is a compromise between conspicuous and concealing colourations. Usually the females show cryptic colouration, while the males exhibit conspicuous colours. Both the sexes, in some forms, acquire *nuptial plumage* by a prenuptial moult and return to dull colour by a postnuptial moult. There is a general tendency to match the colour of the body with the hues of the surroundings. Birds inhabiting the arid zones become pale-coloured, while those of humid regions are darker. The cryptic colouration in birds has a selective value. It adds one or both the sexes the garments which are used for communication between individuals of the same species for pair formation, aggression between males, selection of nest site for laying the eggs and rearing the youngs.

The colours in birds are produced partly by pigments and partly by diffraction effects. Melanins, are the most common pigments which are laid down in the feathers by specialised pigment cells in the feather papillae. The processes of these cells convey the pigment to the epidermal cells. Yellow *xanthophyll* in the beak of duck and red *astaxanthin* of pheasant wattles are carotenoid pigments which are soluble in organic solvents. The white colour is produced by reflection. Two peculiar pigments are recorded in birds. The turacos (plantain-eaters of Africa) contain two pigments: (*i*) *Turacin*—a copper containing red porphyrin and (*ii*) *Turacoverdin*—an iron containing green pigment. The iridescent feathers are due to interference of light in thin surfaces.

SKELETAL STRUCTURES

Exoskeleton

The exoskeletal structures are well-developed in birds. The feathers constitute the major exoskeletal structures. Besides feathers, the other exoskeletal structures are the scales covering the leg and feet, claws and beak. The structural construction of these structures has been discussed in the biology of *Columba*. The modifications of these structures in various birds are discussed below.

Modifications of beak. The beak is essentially a structure to obtain food, to preen feathers, to collect nest materials to build the nests and also to act as the organ of defence. Because of the functional diversities, the beaks have undergone extensive range of modifications in different birds. Fig. 8.30 shows a few varieties of beak in birds. The modifications of beak are essentially adaptive in nature and the form indicates the food habits.

The beak is strong and powerful in carnivorous birds, being slender in others. In Egyptian vulture the beak is hooked to tear flesh from carcases (Fig. 8.30A). The beak with the marginal hooks and leaflets in Flamingo form a filter-feeding apparatus to sieve small materials from water (Fig. 8.30B). In pacific passerine the beak is modified to collect nectar from the flower (Fig. 8.30C). The beak of passerine cross-bill (Fig. 8.30D) has obliquely crossed mandibles to facilitate the breaking of seed. The beak of woodpecker (Fig. 8.30E) is strongly built and acts as a pick-axe for excavating the wood to get insects. The beak of Albatross (Fig. 8.30F) is large and tube like. The beak of Pelican (Fig. 8.30G) is highly modified to catch fishes. The terminal hooks and the beak pouch are specialised devices for the purpose. The beak of European Goosander (Fig. 8.30H) possesses fish-holding denticulations. The serrations in beak of Catfish (Fig. 8.30I) act as a saw through the petioles of leaves to decorate the display-ground with the green leaves. The Galapagos Woodpecker-finch has a short beak to trench the tree (Fig. 8.30J) with the help of a cactus spine. The cactus spine is hold by the beak to probe the barks for insects. This bird is remarkable for tool-making. The Frogmouth (Fig. 8.30K) has a wide gap between the upper and lower beaks to facilitate insect catching. A tuft of filamentous feathers surmounting the beak also help in the process.

The beak of ducks and geese is flat and broad. It has lateral straining devices. The beak of Parrots is moved on the skull and has sharp edge.

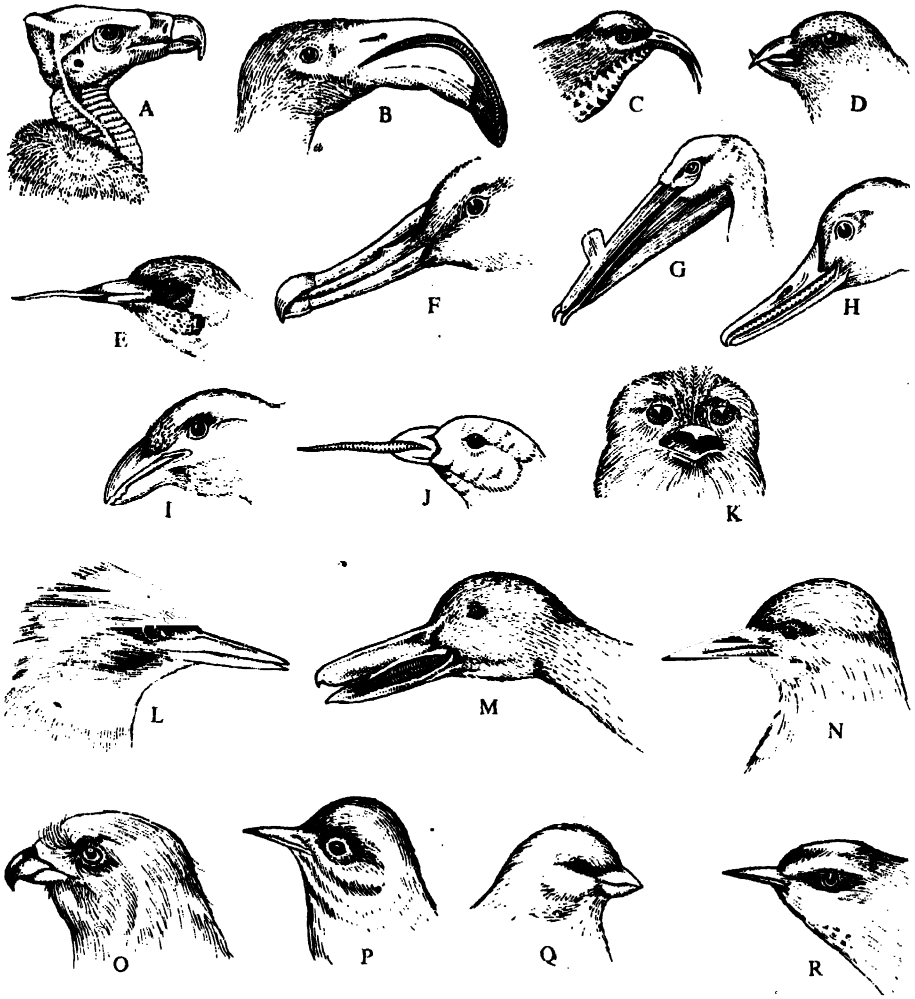


Fig. 8.30. Modifications of beak in different birds. A. Egyptian Vulture. B. Greater Flamingo. C. Pacific Passerine. D. Passerine Crossbill. E. European Green Woodpecker. F. Albatross. G. North American White Pelican. H. European Goosander. I. Australian Tooth-billed Catbird. J. Golapagos Woodpecker-finch. K. Australian Tawny Frogmouth. L. Kingfisher. M. Shoveler. N. Flicker. O. Hawk. P. Thrush. Q. Bunting. R. Warbler.

Modifications of wing. The forelimbs of all birds have modified into the wings. Essentially the wings are built on the same structural plan. As a rule the wings are extremely reduced in ratites and secondarily flightless forms. Like that of *Columba*, all the three digits of the wings are clawless. But in *Chauna* (crested Screamer) and common fowl and goose (abnormal occurrence) claw may be present on the first digit. In the youngs of Hoatzin two clawed digits are present in each wing. But the ratites have retained claws in the digits. The ostriches have claws in all the digits, the rheas possess claws on the first and rarely on the second and third ones. The cassowaries, kiwis and emu have claw only on the second digit (see Fig. 8.37B).

Modifications of feet. The hindlimbs are principally used in movement upon the surface of the earth. The hindlimbs exhibit great diversity in structure according to their mode of action. Broadly the hindlimbs are distinguished into two categories: walking feet and wading feet. The walking feet vary considerably and four toes are usually present. The first toe is directed backward. The walking feet are completely feathered at least up to the tarsal articulation, while the wading feet have partly or completely unfeathered tibial region. The wading feet are found in aquatic birds. The toes are usually webbed to help swimming. The walking feet become specialised for various purposes. The toes are modified for grasping the prey, for perching, for climbling and for offense. The wading feet show different gradations as regards to structure: (*i*) *Swimming feet*—having three anteriorly directed toes connected by undivided web as we see in *Anas*. (*ii*) *Half-swimming feet* having the web extended up to the middle of the toes as observed in *Recurvirostra*. (*iii*) *Split-swimming feet*—the toes have a cutaneous border as seen in *Podicipes*. The border of the toes is lobed in some cases.

Fig. 8.31 shows some instances of pedal specialisations in flying birds. In Cormorant the feet are modified for swimming and defence. In Megapode, the feet are heavily built and adapted for food-getting, running and defence. The claws are sharp In Grebe, the feet belong to half-swimming type, where the toes are laterally lobed. The feet of Jungle fowl of India are modified for running and scratching the soil for search of food. The spur is used for aggression and defence. The grasping feet are examplified by the Hawk where the claws are recurved and the toes have rough raised pads to grasp the prey. The feet are also modified for perching and defence. Similar condition is also observed in Kingfisher. Typical passerine feet are modified for perching, hopping and defence. In Weavers and some other passerine birds, the feet are employed to weave the nestling materials. The feet of sand-grouse are peculiar. They help in thermo-regulation in addition to the normal functions of running and defence. The feet of swift are modified to cling to the vertical surface of the trees or walls by curved claws. Similar modifications are observed in the feet of Woodpecker. In Jacanas, the modification of the toes is remarkable. The toes are unwebbed, but extremely elongated and clawed to ski over unstable floating leaves of water-lilies. In some birds, e.g.,

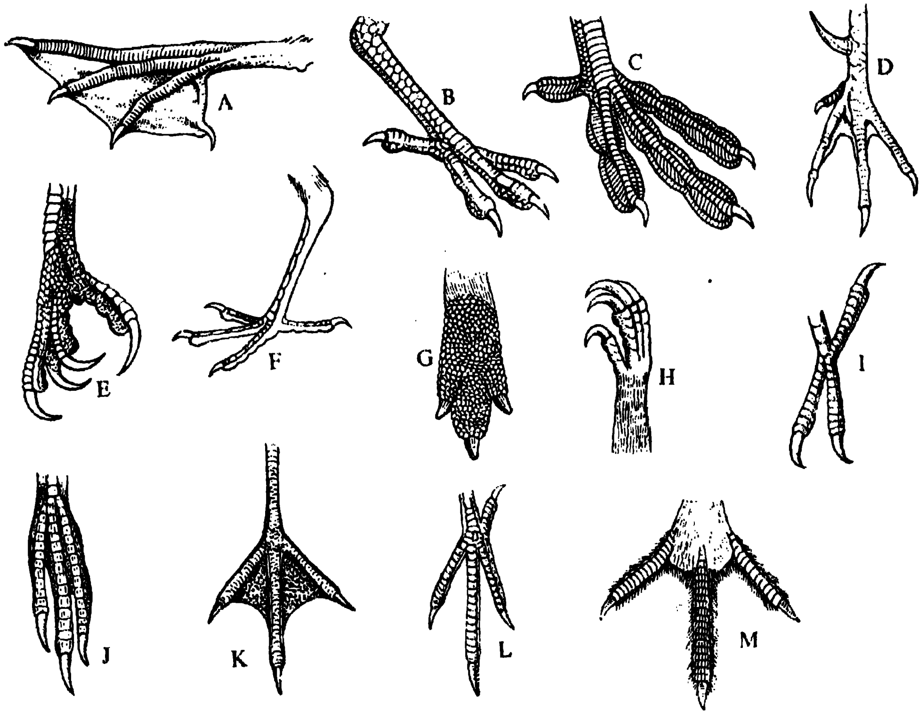


Fig. 8.31. Specialisations of hindlimbs in different birds. A. Cormorant. B. Megapode of New Guinea. C. Grebe of Africa. D. Jungle Fowl of India. E. Hawk. F. Weaver of Africa. G. Sand-grouse. H. Swift. I. Woodpecker (three-toed). J. Kingfisher. K. Avocot. L. Poorwill. M. Sage Cock.

owls, nightjars and some aquatic forms like bitterns, cormorants, gannets, one of the claws in each foot becomes pectinated. This comb-like feather-cleasing structure is highly developed in bitterns. In moth-eating nightjars, this pectinated claws help to clear moth scales from the tactile feathers round the mouth. The pectinated toilet claws are adaptive features and are encountered in unrelated forms. It occurs in species that feed on mucus-coated aquatic or semi-aquatic organisms.

Endoskeleton

The endoskeletal framework is greatly modified in birds for carrying the weight of the body in two distinct ways—during flight on the wings and during rest on the legs. For this purpose, the axial as well as the appendicular skeleton becomes extremely altered.

Skull. The axis of bird is strikingly shorter than any other vertebrate. But the neck remains long in most cases. Avian skull is essentially uniform throughout the class. The following features characterised the avian skull: (*i*) The bones of the skull are fused together resulting in the obliteration of the sutures. These sutures are present in the skull of most ratites. (*ii*) The facial portion is prolonged into a beak composed mainly of large tri-radiate premaxillae. (*iii*) The occipital condyle is single and rounded. The condyle is formed by the basioccipital. (*iv*) A spacious rounded

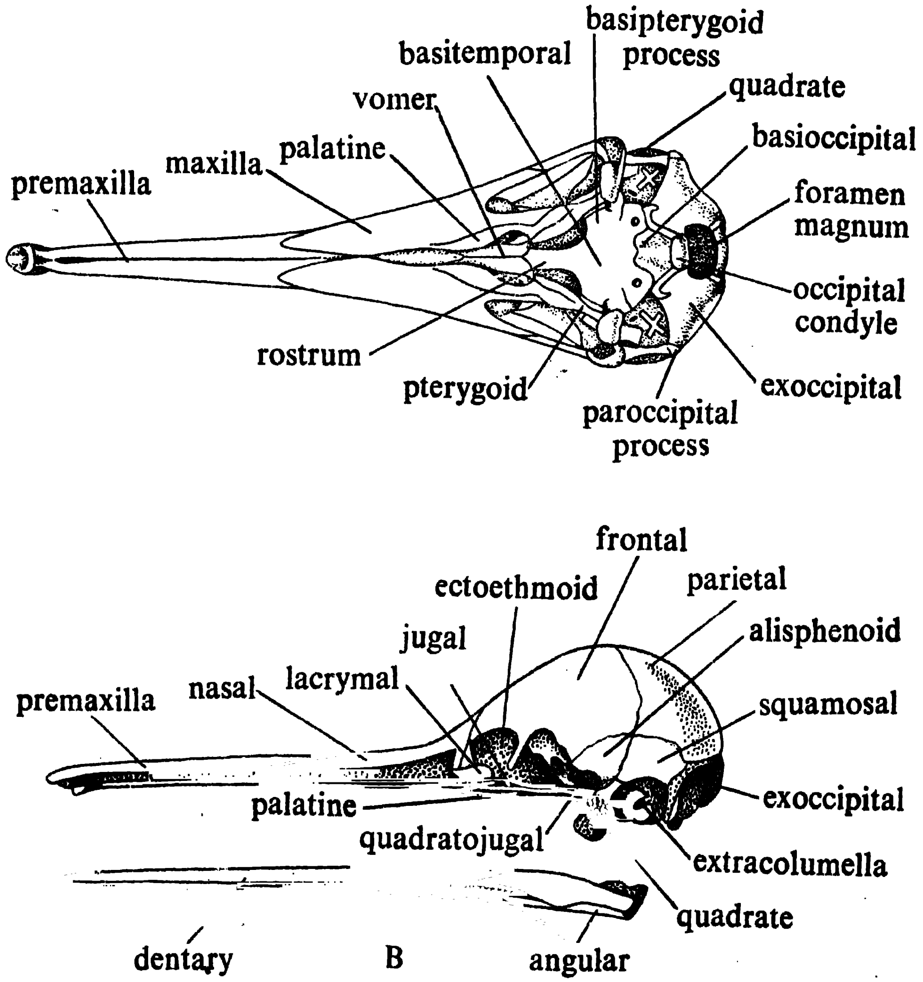

basipterygoid process
basitemporal
quadrate
vomer
basioccipital
palatine
maxilla
premaxilla
foramen magnum
occipital condyle
rostrum
pterygoid
exoccipital
paroccipital process
frontal
ectoethmoid
parietal
jugal
alisphenoid
premaxilla
nasal
lacrymal
squamosal
exoccipital
palatine
quadratojugal
extracolumella
quadrate
dentary
B
angular

Fig. 8.32. Skull of *Apteryx*. A. Ventral view. B. Lateral view.

brain-case. (*v*) The orbits are large except in *Apteryx*. The orbits are separated by a thin interorbital septum formed anteriorly by the mesethmoid which is continued anteriorly with the cartilaginous internasal septum. (*vi*) Rod-like jugal and quadratojugal reach the quadrate posteriorly. (*vi*) The quadrate is freely articulated. (*vii*) The infraorbital arcade is complete, while the supratemporal arcade is mostly incomplete. (*viii*) A large parasphenoidal rostrum is present. (*ix*) Prefrontals and postfrontals are absent and the orbit is not closed from the temporal fossa. But in parrots, a backwardly directed process of the lacrymal meets the postorbital process of the frontal beneath the orbit. (*x*) The squamosal is closely united with the skull. (*xi*) Secondary palate is absent. These are some of the characteristics which are almost universal in most of the forms. But a detailed study reveals many differences, especially the arrangements of the palatal bones. Four distinct broad categories of avian skull are observed. These are: (1) *Dromaeognathous skull*. This type of skull is seen in ratites and *Tinamus*. The basipterygoid processes are large which spring from the basisphenoid to articulate with the posterior ends of the pterygoids. The vomer is large and broad (Fig. 8.32A). The palatines do not articulate with the rostrum. The maxillo-palatine processes are small and do not unite with one another. (2) *Schizognathous skull*. This type of skull is found in gulls, penguins, fowls, pigeon, etc. The vomer is small and pointed in front. But in pigeons, the vomer is absent The basipterygoid processes may be absent or spring from the base of rostrum The maxillo-palatines do not unite one another and the vomer. Fig. 8.33 shows the details of a typical schizognathous type of skull. (3) *Aegithognathous skull*. In passerines, swifts, the skull is almost similar to the schizognathous type, but the vomer is broad and truncated in front. The skull of crow shows the typical condition. (4) *Desmognathous skull*. The vomer is small and the maxillo-palatines are large and spongy (Fig. 8.34). These bones unite with one another in the middle line ventral to the vomer. This type of skull is found in storks, birds of prey, ducks, geese, parrots,

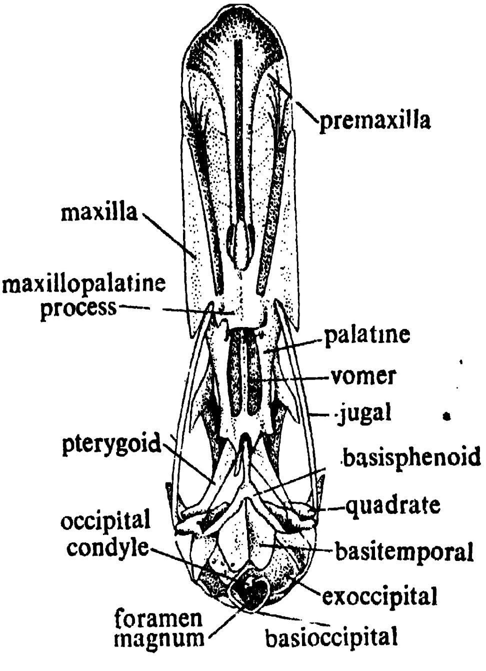

premaxilla
maxilla
maxillopalatine process
palatine
vomer
jugal
pterygoid
basisphenoid
quadrate
occipital condyle
basitemporal
exoccipital
foramen magnum
basioccipital

Fig 8.34. Skull of *Anas* (Ventral view).

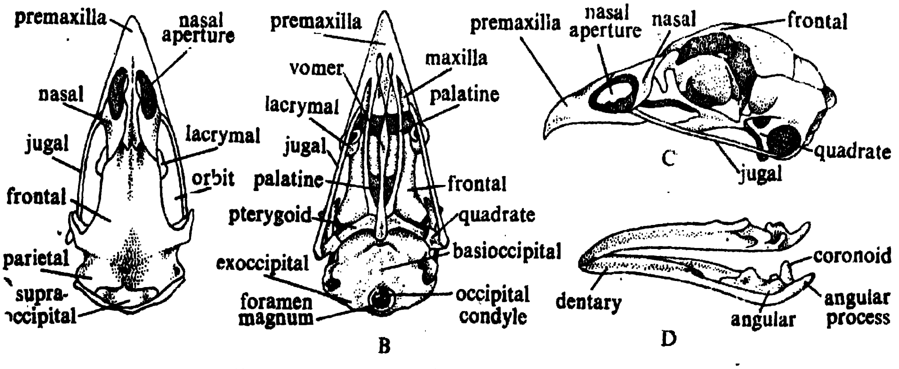

premaxilla
nasal aperture
nasal
jugal
lacrymal
orbit
frontal
parietal
supra-occipital
premaxilla
vomer
maxilla
lacrymal
palatine
jugal
palatine
frontal
pterygoid
quadrate
exoccipital
basioccipital
foramen magnum
occipital condyle
B
premaxilla
nasal aperture
nasal
frontal
C
quadrate
jugal
coronoid
dentary
angular
angular process
D

Fig. 8.33. Skull of *Gallus*. A. Dorsal view. B. Ventral view. C. Lateral view. D. Lower jaw.

etc. In parrots (Fig. 8.35) the skull is peculiar by having movable upper beak. A true craniofacial hinge is present between the skull and upper beak.

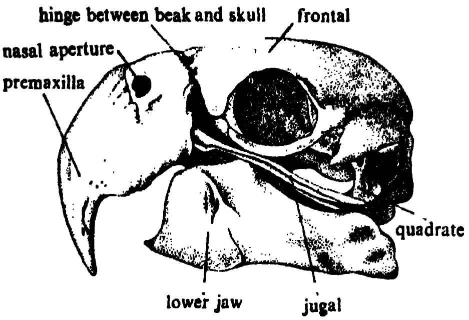


Fig. 8.35. Skull of *Psittacula* (lateral view).

Vertebral column. The vertebral column is highly modified in birds to offer strength and rigidity. The cervical and thoracic vertebrae have heterococlous centra for universal mobility of the neck. The number of different vertebrae is variable in different birds. The number of cervical vertebrae ranges from nine (in song-birds) to twenty-five (in swans). The thoracic vertebrae become more or less fused to form rigid thoracic basket. The thoracic vertebrae are opisthocoelous in penguins, gulls, cormorants, stone-curlews and godwits. The posterior cervical vertebrae and anterior thoracic vertebrae bear *hypophyses* for the attachment of neck muscles. The posterior vertebrae become fused in all the birds to give mechanical strength. The synsacrum is formed by the fusion of posterior thoracic, lumbar, sacral and anterior-caudal vertebrae. The number of sacral vertebrae ranges from one to five. In all living birds except some ratites, a laterally compressed *pygostyle* is present. This ploughshare-shaped bony plate is formed by the fusion of four to six caudal vertebrae.

The centra of the movable vertebrae in birds are separated by *synovial cavities*. Each such cavity is traversed by fibro-cartilage called the *meniscus* which bears a pore through which passes a fibrous cord—the remnant of the embryonic notochord.

Ribs. The thoracic vertebrae carry ribs. Each rib is double-headed. The capitulum is attached to the centrum and the tuberculum joins with the transverse process. Each rib consists of a sternal portion and a vertebral portion. These two portions are united by *synovial joint*. The vertebral portions of ribs possess backwardly directed *uncinate processes*.

Sternum. The sternum is a broad plate covering the ventral side of thorax and part of abdomen. In carinates, the sternum bears on its ventral side an antero-posterior *keel* for the attachment of the pectoral muscles. In ratites, the keel is either absent or represented as a vestige and the sternum thus appears raft-like. In many carinates, the keel becomes reduced and small as in *Notornis*, *Gallirallus* and is almost absent in *Didus*, *Strigops*, *Hesperornis*, etc. The anterior margin of the sternum produces antero-posterior processes, while the postero-lateral part is usually fenestrated or showing deep notches. The development of keel in birds is correlated with the power of flight, it is well developed in flying forms and absent or reduced in flightless members. So the absence of keel in birds is purely adaptive in nature having no phylogenetic significance.

Girdles and limbs. Both the girdles and limbs have become greatly modified for flying and walking. The *pectoral girdle* exhibits adaptive divergence in ratites and non-ratites. In ratites, the scapula and coracoid are small and fused with one another. But in non-ratites the scapula and coracoid are large and are united by ligament. In these forms the scapula bears an acromian and the coracoid has an acrocoracoid process. Both these processes are either absent or extremely reduced in ratites. The coracoscapular angle is usually less than 90° in non-ratites, but in ratites this angle approaches two right angles. Another peculiarity is the absence of furcula in ratites. In most of the non-ratites the furcula (probably consisting of clavicles and interclavicles) is loosely attached with the anterior end of the sternum. The skeleton of the *wing* becomes greatly altered from the typical vertebrate plan. Fusion of terminal bones to limit the movable joints has increased the efficiency of the wings. The peculiarities of the wing-skeleton have already been discussed in the biology of *Columba*. In ratites and other flightless birds the structure of the wing has become reduced. In penguins, due to the transformation of the wings into swimming paddles, the bones have become flattened and a sesamoid bone called the *patella ulnaris* replaces the olecranon process. The wing bones are reduced in *Hesperornis*, but in *Moas*, there is no trace of wing skeleton.

The *pelvic girdle* and *legs* have become specialised for standing, walking, perching and swimming. The pelvic girdle has well-developed expanded ilia which are attached to the sacrum. The ischia are directed backward. The pubes are slender bones. In Apteryx, the pubis and ischium are entirely free, while in cassowaries and emu the pubis and ischium are united with the posterior end of the ilium. The pubes and ischia remain separate in most birds but in ostrich the pubes are united by symphysis, while in *Rhea* there is an ischiatic symphysis. The ischia, pubes and ilia participate in the formation of acetabulum which is perforated. The pubis in Apteryx is peculiar by having a forwardly directed *pectinal process*. The bones of the hindlimbs exhibit less diversity in different birds except penguins where the tarsometatarsus is short and broad. Three metatarsals composing each tarsometatarsus are easily distinguishable from outside. There are four digits in the leg of birds. No bird possesses the fifth digit in adult. A vestige of the metatarsal of the fifth digit is found in the embryo of some birds.

As already been discussed, the endoskeleton has become modified mostly for aerial movement. The bones have become light due to the extension of the air-sacs in majority of the birds except some diving forms. Pneumacity of the bones shows regional specificity. In most of the birds all the bones are pneumatic except forearm, hand, shank and foot. In penguins, Apteryx and many song-birds only the skull bones are pneumatic to make the skull light. In birds the bones are pneumatic without reducing the mechanical strength of the bones.

DIGESTIVE SYSTEM

Despite great diversities in the mode of feeding, the digestive system in birds shows uniformity throughout the class. The mouth is bounded by upper and lower jaws which are covered by rhamphotheca to form the beak. The rhamphotheca is mostly simple, while in ratites it is compound. The beak has assumed extensive variations which are correlated to the feeding habits of the birds. Teeth are absent in all modern birds. The tongue is long and thin. It contains taste-buds and mucous glands. There are three salivary glands—one medium sublingual and two angular glands which usually produce saliva to moisten the food. In graminivorous birds, the saliva contains diastatic enzyme.

The buccal cavity is usually small in birds, but in some forms, especially pelicans, the floor of the buccal cavity is dilated to form a large *gular pouch* to store fishes. The pharynx leads into a wide oesophagus, which produces a large receptacle (crop) in grain-eating birds. The crop stores a large quantity of food and produces 'crop-milk' during breeding season. The oesophagus leads into the stomach which is divided into a tubular glandular proventiculus and a muscular gizzard. The gizzard is highly muscular in grain-eating forms, while in carnivorous forms it is simple and assumes the characters of normal stomach. The duodenum and the coiled intestine are short in carnivorous birds, but in grain-eating varieties these are elongated. The duodenum receives the pancreatic and bile ducts. The gall bladder is present in most birds, but in a few forms (as in *Columba*) the gall bladder is totally lacking. Two small blind *caeca* are present at the junction of the ileum and rectum. The caeca play two functions: digestion of vegetable fibres by bacterial and/or enzymatic action and help in the absorption of water. The elaboration of the cloacal chamber into the coprodaeum, urodaeum and proctodaeum helps in reabsorption of water. The bursa fabricii ("cloacal thymus") opening into the proctodaeum helps the young birds to protect against local infection. It becomes extremely reduced or atrophied in adult.

RESPIRATORY SYSTEM AND SOUND PRODUCING ORGAN

The respiratory system is remarkably modified to provide large supply of oxygen necessary for active metabolism. The lungs are proportionately small in size and slightly distensible. The functional efficiency of lungs is enhanced largely by the development of air-sacs. The air-sacs play important role in the life of birds. These sacs become greatly reduced in ratites and other flightless forms.

The glottis is slit-like and situated posterior to the root of tongue. The glottis leads into larynx which cannot produce any sound. The sound is produced by a specialised apparatus called the *syrinx* or *lower larynx*. This appratus is simply constructed in many birds, but the associated muscles become very complicated in the 'song-birds' (order Passeriformes). Most birds can produce calls and songs. The parrots, magpies, mocking-birds, mynas and many others possess the inherent capacity of mimicry. The avian notes are used (*i*) to convey different 'ideas' to their fellows; (*ii*) to assemble the individuals of the gregarious species; (*iii*) to attract the mates in chosen territory; (*iv*) to warn at the time of danger and (*v*) for reciprocal directional calls between youngs and parents.

CIRCULATORY SYSTEM

The circulatory system is very efficient to allow birds a high rate of metabolism and a high but constant body temperature. The heart is specially noted by having efficient and powerful forwarding chambers. Complete separation of oxygenated and deoxygenated blood yielded a high arteriolar pressure to allow essential materials to reach the different tissues quickly. The size of the heart and the rate of heart beat depend on the size and activity of the birds. Usually, the larger birds have smaller heart with lower rate of heart beat and this condition is usually reverse in smaller varieties. The rate of heart beat is nearly 500 in sparrow, 300 in hen and less than 100 per minute in a turkey.

The arteries, specially supplying to the wings, are enormously developed. Another characteristic feature of the circulatory system is the considerable reduction of the renal portal system. The red blood corpuscles are oval, nucleated and carry large amount of haemoglobin. The functional efficiency of the R.B.C. in birds is higher than in mammals. In birds, the B.M.R. (Basal Metabolic Rate) and body temperature are considerably higher than that of mammals. The body temperature of birds is usually 42°C reaching nearly to 45°C in some cases. The physiological mechanism of the regulation of constant body temperature in birds is difficult to interprete. The role of air-sacs in the temperature regulation is significant. The air-sacs can conserve heat and can also lose heat by ventilation, when necessary. Loss of heat in birds is also minimised by having avascular extremities.

NERVOUS SYSTEM AND SENSE ORGANS

The brain and the sense organs agree in all essential features with those of Columba already discussed. The eyes show great variation in size. In hunting birds, the eyes are proportionately larger is size. The retina of diurnal birds is composed largely of cones. Nocturnal birds have mainly the rods in the retinal layer. The pit-like fovea exhibits modifications in some cases. The Kingfishers possess double foveas. During diving under water for a catch, the image is transferred from one fovea to the other. Another peculiarity of avian eye is the presence of a pleated projection from the blind spot called the pecten. The pecten is small in nocturnal forms and largest in far-sighted diurnal hunters. In spite of diverse opinions regarding the physiological role of this structure, no general agreement exists on this issue.

URINOGENITAL SYSTEM

The structure and function of kidneys are similar throughout the class. The glomeruli show the general trend of reduction. In sea-birds particularly the penguins and cormorants, bilateral nasal glands are suggested as additional salt-excreting organs. These glands help in extra-renal excretion of sodium chloride from the body.

Fertilization is internal and all birds lay eggs. In ratites, anseriformes and some other birds a penis to assist in internal fertilization is present. The eggs are incubated for the growth of the embryo. The *incubation* period varies in different birds. The youngs may be *precocial* or *altricial*. The absence of right ovary and oviduct is a peculiar occurrence in avian anatomy. Some birds, e.g., hawks, both the ovaries are functional.

Reproduction in birds is usually a seasonal phenomenon. The gonads increase in size and become functional during the breeding activities which are controlled by the endocrine system. Many species exhibit courting performances during breeding season. A few land birds lay eggs on bare rocks or ground and others build nest for the eggs and youngs.

ORIGIN OF BIRDS

Birds constitute a very specialised group of vertebrates which have evolved from reptiles during Mesozoic era. The actual documentary records of the stages how such reptiles were transformed into birds are rare because of the nonavailability of abun-

dant avian fossils. Two fossil specimens of *Archaeopteryx* discovered from the upper Jurassic beds added the strongest evidence to this contention. Being fully avian in its organisation, this fossil bird retained in its anatomy many features which are unmistakably reptilian (Fig. 8.36). This admixture of avian characteristics in one hand and the reptilian features on the other justifies Archaeopteryx as a 'connecting-link' between the reptiles and birds.

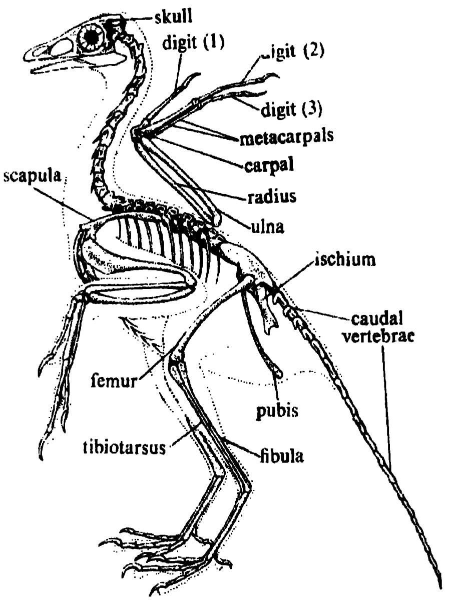


Fig. 8.36. Skeleton of *Archaeopteryx*. Note the presence of toothed rostrum, sclerotic ossicles and well-developed tail.

Reptilian features—evidences in favour of reptilian origin of birds

Reptiles and birds appear quite different from external examination, but closer examination will reveal that both these classes of vertebrates are basically similar. Birds are basically reptilian and the characters which distinguish a bird from a reptile are due to its adaptation to aerial life. Because of this close similarities, T. H. Huxley called the *birds as the glorified reptiles* and included both the classes under the superclass *Sauropsida*. The evidences in favour of reptilian origin may be catalogued in the following ways: Anatomical, Embryological and Palaeontological evidences.

Anatomical evidences. (1) Both reptiles and birds have well-formed exoskeletal structures—scales in reptiles and feathers in birds. The hindlimbs, in majority of the birds, are covered by scales which are typically reptilian in structure, orientation and origin. The feathers are modified scales. (2) Although the claws in birds show wide structural diversities, these structures are typically reptilian, being constructed of a dorsal unguis and a ventral subunguis. (3) The exoskeletal structures including the horny covering of the beak in birds are shed. This process resembles closely the moulting phenomenon—the diagnostic feature of reptiles. (4) Beak-like structure is present in many reptiles. (5) The skull is autostylic with distinct quadrate. (6) The occipital condyle is single and developed from basioccipital. (7) The interorbital septum is present in birds and reptiles except snakes and limbless lizards. (8) The sclerotic plates are present. (9) The mandible is complex—being composed of several pieces of bones. (10) Both cervical and thoracic ribs are present. (11) The uncinate processes (avian features) are found in the ribs of the crocodiles and Sphenodon. (12) The skeletal frame of the hindlimbs is strikingly similar in both reptiles and birds. The phalanges are typically reptilian (2, 3, 4, 5). The wings of some ratites contain one or two digits ending in claws. (13) The gizzard is present in birds and crocodiles. (14) The caecum is present. (15) The cloaca is an elaborated chamber in both the classes to reabsorb water from the urine. Although the cloaca is incompletely divided into three chambers in birds, the hint of division is observed in reptilian cloaca. (16) The trachea is made up of complete tracheal rings. (17) The air-sacs are present in birds and chameleon. (18) Avian heart is four chambered. The heart of crocodiles is almost four chambered (the foramen of Panizza is insignificant). (19) The red blood corpuscles are oval and nucleated in both the classes. Scott has shown that the avian and reptilian blood shows close affinities from the serological examination. (20) Single avian aortic arch on the right side is a modification of the reptilian aortic arch. In crocodiles, the right aortic arch is predominent. (21) The kidneys are elongated and are of metanephric type. (22) Urinary bladder is absent in birds and snakes. (23) Both reptiles and birds are oviparous and the fertilization occurs internally. (24) The oviducts are regionally differentiated into different glandular areas. (25) Intromittent organs are present in reptiles (except Sphenodon) and in ratites and ducks. (26) The neopallium is smooth in both the classes. (27) The cerebellum of bird and crocodiles shows close structural similarities. In both the cases, the cerebellum is divided into a medium vermis and two lateral flocculi. (28) Twelve pairs of cranial nerves are present (except snake). (29) The pecten is present in the eyes of birds and crocodiles. (30) The ciliary and sphincter muscles of the iris have striped fibres.

Embryological evidences. The developmental

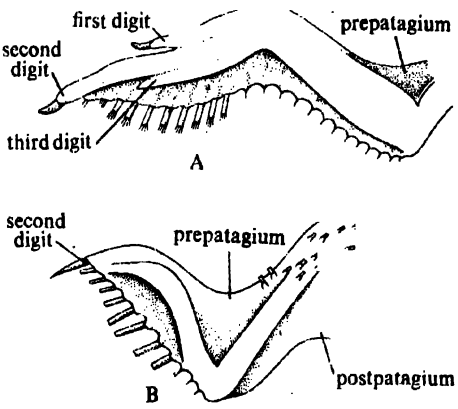


Fig. 8.37. A. Clawed wing of nestling *Opisthocomus*. Note the presence of two clawed digits. B. Wing of adult *Apteryx*. Note the presence of one clawed digit.

history of both reptiles and birds throws light on the phylogenetic interrelationship between them. The evidences are: (1) The sperms are closely similar in size, shape and structure. (2) The eggs are large, albuminous, telolecithal and covered by hard egg shell. (3) Development depends upon incubation in both. (4) The segmentation is meroblastic. (5) The mechanism of gastrulation and mesoderm formation is similar. (6) Extraembryonic membranes, amnion and chorion are present. (7) The developmental stages of scales and feathers are closely similar. (8) The wings lack clawed digits. But in ratites, clawed digits may be present. But in the embryonic stage of *Opisthocomus*, claw is present in the wing. (Fig. 8.37). (9) The organ of Jacobson is present in the embryonic stage of birds. (10) The interclavicle is present in the embryonic pectoral girdle of birds.

Palaeontological evidences. The palaeontological studies of fossil birds and reptiles give strongest support to the reptilian ancestry of birds.

Similarities between fossil birds and modern reptiles.

The earliest known fossil bird, *Archaeopteryx*, was obtained from the upper Jurassic bed of Solentofen in Bavaria, Germany. Due to the blending of avian and reptilian characters, Archaeopteryx serves as an instance of mosaic evolution and is regarded as a missing link between the reptiles and modern birds.

Von Meyer obtained for the first time the fossil of a feather and named the bird which possessed it as *Archaeopteryx lithographica*. Andres Wagner discovered the entire fossil and named it as *Griphosaurus macrura*. A second fossil was discovered by Daves from the same bed. Following are the salient features of the bird: (1) The size was slightly larger than crow. (2) The axis of the body was elongated and lizard-like. (3) The vertebrae had amphicoelous centra. (4) A long tail was present which was composed of 18 20 caudal vertebrae. The tail had parallel rows of rectrices along its sides. (5) The forelimbs had three clawed digits with separate metacarpals and phalanges. The hallux was opposable. (6) The wing area was small having rounded shape. The feathers were present on the back of ulna and hand. (7) The ribs were slender and devoid of uncinate processes. Abdominal ribs were present. (8) The pectoral girdle had a distinct 'T'-shaped interclavicle. The coracoid and scapula were slender. The furcula was a 'U'-shaped bone. The sternum was small. (9) The pelvic girdle had elongated ilia and backwardly directed pubes. The ischia were thin, each had a foramen. (10) Each hindlimb had four clawed digits and the phalangeal formula was 2, 3, 4, 5. (11) The shape of the skull was more reptilian with a single occipital condyle, large brain case, fairly developed zygomatic arch and completely fused parietals. (12) A circle of sclerotic ossicles was present. (13) Well-developed short and blunt beak was present with well-formed conical teeth lodged in sockets. (14) Cerebral hemispheres were elongated and the cerebellum was small.

The available fossils of Archaeopteryx gave only the impression of exoskeletal and endoskeletal structures and nothing was possible to know about the soft parts. Despite this limitation, these fossils suggested that the birds originated from reptiles. Besides the fossils of Archaeopteryx, other fossil birds of Cretaceous period (*Hesperornis*, *Baptornis*, *Ichthyornis*, *Apatornis*, etc.) showed many reptilian features. These fossil birds were all diving and swimming forms exploring the harvest of the sea. The discovery of all these fossil birds proclaimed the reptilian ancestry of birds.

Similarities between fossil reptiles and modern birds

Many fossil reptiles have attempted to aerial life and underwent structural modifications for that particular mode of living. These fossil reptiles showed many avian features.

Euparkeria. This small pseudosuchian reptile of early Triassic period had foreshadowed the essential characteristics of the avian life. The skull was long and slim suggesting the existence of a beak-like structure. Sharp teeth were present in sockets along the edges of the jaws. The hindlimbs were longer and showed the dawn of bipedal habit. According to most of the palaeontologists, this form of fossil bipedal reptile gave origin to birds. The changes undergone by the birds during their evolution from such reptilian stem-form have been reflected by the descendants of the pseudosuchians—like the Dinosaurs and Pterosaurs.

Dinosaurs. These Mesozoic creatures were diverged into two lines—Saurischians and Ornithischians. The Saurischians possessed triradiate pelvis. The ostrich-dinosaur (*Struthiomimus*) was bipedal reptile and walked on three toes. The bones were hollow: The skull was heavily built with a beak-like structure. The number and size of teeth were greatly reduced. The ornithischians or 'bird-like' dinosaurs possessed essentially avian pelvis. A 'predentary' bone was present in the mandible to support the horny beak. They were bipedal forms. The beak was either edentulous or the teeth were restricted to the hinder part of the beak. The digits of the forelimb became reduced to three and were possibly modified for grasping.

Pterosaurs. The pterosaurs examplified by *Rhamphorhynchus*, *Pteranodon*, *Pterodactylus* showed many avian features. The bones were light and pneumatic. A beak was present and the teeth were absent in latter forms. The sutures of the skull were obliterated. Two temporal openings were present behind the large eyes. A large preorbital foramen was present. The neck was fairly long and flexible. Series of ribs were present between pectoral and pelvic girdles. Cervical ribs were double-headed. Both the girdles showed avian similarities. The sternum was large with a keel. The wings were present in the form of patagia. The humerus was strong, the radio-ulna was elongated. Only four digits were present and there was no trace of fifth digit. The first, second and third digits were small and the fourth one was extremely elongated as the 'wing-finger' to support the patagium. The cerebellum was large as evidenced from brain-cast.

The similarities between the fossil reptiles and modern birds are due to their adaptive convergence for similar mode of living. The cumulative evidences from all sides added more weight to the idea that the reptiles and birds are phylogenetically related with one another.

Origin of flight in birds

The rise of the major groups of vertebrates is always associated with functional changes. The evolution of the birds is associated with the changes from terrestrial to aerial life. The reptilian ancestry of birds is a self-evident fact, but detailed evidence of the steps how cold-blooded terrestrial reptiles were converted into warm-blood flying birds are insufficiently known except the discovery of a fossil bird, *Archaeopteryx* in the Jurassic bed. Lack of sufficient transitional types between the reptiles and birds, discussion on the origin of birds has taken the form of theories as to how flight started in birds.

Cursorial origin. Nopcsa has advocated the cursorial origin of birds. According to him, the proaves was a running reptile. While running fast on the ground this reptile lifted the forelimbs off from the ground. The scales over the margin of the limbs become expanded as feathers. Nopcsa believed that birds arose from bipedal dinosaur-like reptiles which used to run on the ground by the hindlimbs. During this mode of progression the head was always raised sufficiently high up the ground and the forelimbs were stretched out to maintain balance.

Arboreal origin. Birds evolved from arboreal reptiles. This concept is supported by many ornithologists. Proaves was arboreal forms which used to live on trees. Osborn put forward the *"pair-wing theory"* and advocated that only the forelimbs were utilised in climbing the trees and also during jumping from one tree to another. This have led to the origin of patagia between the limbs and the body. Beebe and Heilmann established the *"four-wing theory"* which signifies that both the fore- and hindlimbs were used during the process. Both the pairs of the limbs were utilised for climbing the trees also during parachuting from tree to the ground and from tree to tree. Gregory advanced a *compromise idea* and regarded that proaves was good runner both on ground and on trees.

Diving origin. Newman regarded the proaves as aquatic reptile. Flight might have started in connection with soaring over the water during diving for fishes.

Much controversy exists about the origin of flight in birds. The structural construction, specially the claws and long tail of Archaeopteryx added evidence in favour of gliding origin of flight in birds. During Mesozoic era, birds originated from a race of bipedal arboreal reptiles which were accustomed to run, jump and glide on the branches of the trees.

Probable line of origin

The reptilian origin of birds is an undisputed question. The anatomical, embryological and palaeontological evidences are most convincing with respect to the phylogeny of birds. The palaeontological evidences have established that archisaurian diapsids hold the key of avian origin. The ancestral form was closely allied to *Euparkeria* of Triassic period during Mesozoic era. From such a bipedal stem form, the birds have evolved in space and time. Two factors appear to be crucial which lead the pro-avian reptiles to be glorified as birds. These two factors are: (1) search for food and (2) search for safety.

MIGRATION OF BIRDS

The word migration has come from the latin word *migrara* which means going from one place to another. Many birds have the inherent quality to move from one place to another to obtain the advantages of the favourable condition. In birds, migration means two way journeys—onward journey from the 'home' to the 'new' places and back journey from the 'new' places to the 'home'. This movement occurs during the particular period of the year and the birds usually follow the same route. There is a sort of 'internal biological clock' which regulates the phenomenon.

Types of migration

All birds do not migrate, but all species are subject to periodical movements of varying extent. The birds which live in northern part of the hemisphere have greatest migratory power. Migration may be **latitudinal** and **altitudinal.** The latitudinal migration usually means the movement from north to south and *vice versa*. Most birds live in the land masses of the northern temperate and subarctic zones where they get facilities for nesting and feeding during summer. They move towards south during the winter. An opposite but lesser movement also occurs in the southern hemisphere when the seasons are changed. Cuckoo breeds in India and spends the summer at south-east Africa and thus covering a distance of about 1,500 miles. Some tropical birds migrate during rainy season to the outer tropics to breed and return to the central tropics in dry season. Many marine birds also make considerable migration. *Puffinus* (Great shearwater) breeds on small islands and migrates as far as Greenland in May and return back after few months. It covers a distance of 800 miles. Penguins migrate by swimming and cover a considerable distance of few hundred miles. *Sterna* (Arctic tern) breeds in the northern temperate region and migrates to the Antarctic zone along the Atlantic. It was observed that Sterna covers a distance of 11,000 miles during migration. The altitudinal migration occurs in mountainous regions. Many birds inhabiting the mountain peaks migrate to low lands during winter. Golden plover (*Pluvialis*) starts from arctic tundra and goes up to the plains of Argentina. Birds migrate either in flocks or in pairs. Swallows and storks migrate a distance of 6,000 miles from Northern Europe to South Africa. Ruff breeds at Siberia and travels to Great Britain, Africa, India and Ceylon thus travelling a distance of 6,000 miles.

Factors controlling migration

Most species of birds migrate more or less on schedule and follow the routes in a regular fashion. The actual causative factors determining the course and direction of migration are not clearly known. Migration in birds depends upon two important factors—stimulus and guidance. Scarcity of food and fall of daylight are believed to produce endocrinal changes which initiate bird migration. The guidance during migration is chiefly instructive but various factors are believed to act as guide. Matthews (1955) and Sauer (1957) have emphasised the position of the sun (during daytime) or stars (during night) helps the birds to navigate along definite route. Experimental evidences by creating artificial planatorium have shown that the shifting of the position of sun causes a change of the migratory pathways. Heavy cloud or fog interferes migration during night. Besides, the magnetic intensity; east-west and north-south gradients of gravity; lines of magnetic force; obvious landmarks like coastal lines, rivers, mountain ranges, etc. The north-to-south migrations of birds take place under stimulus from the internal condition of the gonads which are affected by seasonal variation. The experiments of Rowan with Juncos (summer visitor to Canada) have established that light plays important role in the development of gonads which has indirect role on migration. If the gonads undergo regression, the urge for migration is not felt. So the seasonal changes in illumination appear to be a crucial factor determining migration. Despite all these suggestions, it is not clear how birds through successive generations follow the same route and reach the same spot. The instinctive behaviours like migration, breeding, moulting are phasic occurrences in the annual cycle which are possibly controlled by the endocrine system. In all migratory birds, accumulation of fat takes place for extra fuel during prolonged flight in migration.

Problems of migratory birds

Migration is the most adventurous period of avian life. Every year, hundreds of millions of migrants never reach their destination. The following factors create great problem to the migratory birds: storms and hurricanes; strong current of wind; fog: man-made towers and lighthouses.

SUMMARY

(1) Birds are 'heavier-than-air' flying vertebrates. They exhibit double adaptations -the anterior part of the body becomes modified for flying and the posterior portion is specialised for running or climbing or perching or swimming.

(2) One of the striking features of avian life is that the basic organisation remains fairly uniform throughout the class. The anatomy of *Columba* will give a fair picture of avian organisation in general.

(3) Birds are easily recognised by having the body covered by feathers, the forelimbs modified into wings, four-chambered heart with only right aortic arch, well developed lungs with thin-walled air-sacs, twelve pairs of cranial nerves, well developed eyes with pecten, etc.

(4) Birds arose from reptiles and exhibit a significant advancement over the reptiles by having regulated body temperature, high metabolic rate, highly developed sense organs and highly specialised care of the youngs. The discovery of fossil bird, *Archaeopteryx* from the Jurassic bed unequivocally speaks of reptilian ancestry of birds. Because of the reptilian affinities, birds are said to be 'glorified reptiles'.

(5) There are about 8,650 species of birds living today in this world. They exhibit a great variety of special features enabling them to occupy numerous habitats. They show differences in body form, flying ability, instinctive behaviours, shape of beak, feet and many other parts which are purely adaptive in nature.

(6) Birds are classified into two subclasses: Archaeornithes and Neornithes. The older idea of division of the subclass Neornithes into two groups "Ratitae" and 'Carinatae' depending on the flying ability is untenable now-a-days. Because many carinates have become raft-breasted forms due to loss of flight.

(7) Migration is one of the characteristic behaviours in many birds. Migration may be latitudinal and altitudinal and in all the cases such movement is always seasonal.

CHAPTER 9

Phylum Chordata—MAMMALS

Originating from a lowly organised reptilian stalk as tiny and insignificant contemporaries of the gigantic reptiles during the Mesozoic era, mammals by virtue of their superorganised brain came to the top of the ladder of evolution. A wide variety of structure and form is present among the mammals. They range in size from that of a mouse barely one inch in length to that of a whale attaining a length of more than one hundred feet (Fig. 9.1). They have conquered all available habitats.

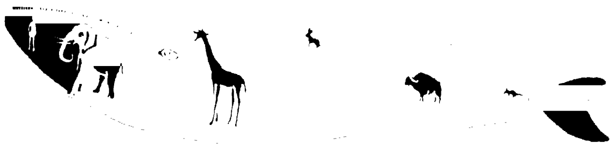


Fig. 9.1. Showing the diversities in form and size of a few mammalian forms. Whale is the largest aquatic animal and the elephant forms the largest terrestrial form.

IMPORTANT FEATURES

(1) Mammals are stenothermal (excepting Monotremes) vertebrates. (2) The body of mammals is covered with epidermal hairs. Hairs are mammalian monopoly. (3) Mammals possess integumentary glands in the form of sweat, sebaceous or ordoriferous glands. (4) Mammary glands are present in mammals and they are functional in adult females. The secretion of mammary gland is known as milk and it is the chief food for suckling youngs. (5) Mammals are quadrupeds but in whales the limbs are absent. (6) The digital tips are provided with claws, nails or hoofs. (7) External ear or pinna is usually present in most mammals. (8) Eyes of mammals are provided with upper and lower eyelids and often eve lashes are associated with the eyelids. (9) The urinary and genital apertures of mammal are separate excepting Monotremes. (10) Internally a diaphragm is present in all mammals. It forms a partition between the thoracic and abdominal cavity. (11) Heart of mammals consists of two auricles and two ventricles. (12) Sinus venosus is absent. (13) Only the left aortic arch is present. (14) Mature red blood corpuscles are non-nucleated. (15) Brain of mammals is highly developed. (16) Cerebral hemisphere is large and much convoluted. (17) Corpus callosum is present in the form of a transverse band of nerve fibres and it forms a bridge between the two cerebral hemispheres. (18) Corpora quadrigemina is present on the dorsal side of the midbrain. (19) Twelve pairs of cranial nerves are present. (20) Occipital condyles are two in number. (21) A bony palate formed by the premaxilla, maxilla and palatine separates the nasal passage from the buccal cavity. (22) The lower jaw or mandible is made up of a single piece of bone called dentary and articulates to the skull through squamosal. (23) Jaws are provided with teeth. The teeth are thecodont, diphyodont and heterodont. (24) The centrum of the vertebra is flat on both the surfaces. (25) Cervical vertebrae are usually seven in number except in sloths. (26) Sternum is segmented. (27) The coracoid of the pectoral girdle is ill developed. (28) Pubic symphysis is present in the pelvic girdle. (29) Mammalian eggs are small and are with little yolk. (30) Fertilization is always internal. (31) Amnion, allantois and chorion are present as embryonic membranes in all mammals excepting Monotremes. Allantois is rudimentary in Marsupials. (32) Placenta is present in Eutherian mammals. (33) Oestrus cycle is present in mature females.

OUTLINE CLASSIFICATION

Living members of the class Mammalia are divided into two principle subclasses. The subclasses being (1) PROTOTHERIA and (2) THERIA. Under subclass Prototheria there is a single order named *Monotremata* which includes egg laying Platypus. Subclass Theria has again been divided into two infraclasses. The infraclasses are (1) METATHERIA and (2) EUTHERIA. Under infraclass Metatheria there is one order named *Marsupialia* which includes the pouched mammals. All placental mammals are included in the infraclass Eutheria. There are sixteen living orders under the infraclass Eutheria. The names of these orders are: (1) *Insectivora*, (2) *Chiroptera*, (3) *Dermoptera*, (4) *Edentata*, (5) *Pholidota*, (6) *Primates*, (7) *Rodentia*, (8) *Lagomorpha*, (9) *Cetacea*, (10) *Carnivora*, (11) *Tubulidentata*, (12) *Hyracoidea*, (13) *Proboscidea*, (14) *Sirenia*, (15) *Perissodactyla* and (16) *Artiodactyla*. Besides these living orders, there are many extinct orders.

EXAMPLE OF MAMMALIA -CAVIA

Cavia porcellus is the scientific name of guineapig. It comes under the order *Rodentia*. Guineapigs are much in demand as useful laboratory animals.

HABIT AND HABITAT

Guineapigs have been made domesticated. Wild guineapigs are almost cosmopolitan in distribution. They are herbivorous and lead a subterranean life. Guineapigs are in the habit of passing food twice through the alimentary canal (Caecotrophy). Faecal pellets passed in the day time are of dry and hard consistency. But those passed in the night are soft with much mucus in them. The guineapigs are in the habit of taking these nocturnal faeces and as such they are called *Coprophagus* animals.

EXTERNAL STRUCTURES

The length of the Cavia is about eight inches from mouth to vent. The body is covered over with variously tinged soft hairs. Certain area of the body is devoid of hair. The body is divisible into three distinct parts, *head*, *neck* and *trunk* (Fig. 9.2). Tail is absent, but the tail bone is perceptable at the posterior end of the trunk. Following structures are found in the three different parts of the body.

Head is short and more or less triangular in appearance. Anteriorly it ends in a pointed *snout*. The snout is devoid of hairs and bears at its tip a pair of apertures called *external nostrils*. Round the nostrils there are several stiff and sensitive whiskers called *vibrissae*. The aperture of mouth is located beneath the nostrils. It is bounded by upper and lower lips. The upper lip has a cleft in the middle through which the upper incisors protrude. Round and large *eyes* are present one on each lateral side of the head. Each eye is provided with three eyelids—upper, lower and third or *nictitating membrane*. Upper and lower eyelids are movable and are provided with *eye-lashes*. Nictitating membrane is a whitish transparent movable curtain oriented obliquely in front of the eye-ball. On each posterior

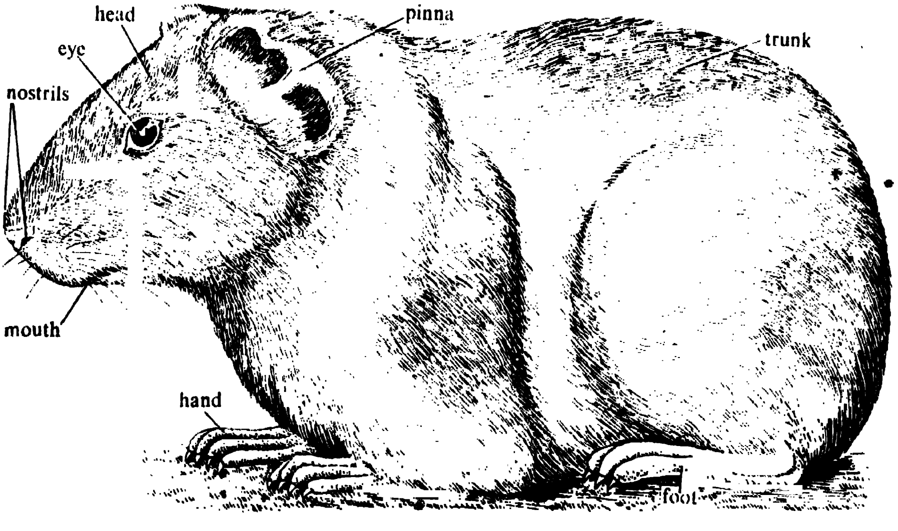


Fig. 9.2. External structures of *Cavia*.

lateral side of the head an elongated flap like movable fold of skin called *pinna* is present.

Neck is short and flexible. It is a sort of bridge between the head and trunk. It permits independent movement of the head.

The cylindrical trunk is divisible into two parts, *thorax* and *abdomen*. Thorax is supported by ribs and sternum but abdomen has no such bony support on the ventral side. The trunk bears paired *mammary glands* at its posterior ventral part. Each gland opens externally through a *teat* (or *nipple*). In males the nipples are poorly developed. *Anus* is present as a small aperture on the posterior end of the trunk. Beneath the anus the *urinary* and *genital apertures* are located. In males there is a common opening for both the systems and the opening is present at the tip of a muscular organ called *penis*. In the female the genital and urinary openings are separate. The trunk is provided with two pairs of limbs, forelimbs and hindlimbs. The hindlimbs are larger than the forelimbs. The limbs are built in a pentadactyle pattern. There are four digits in each forelimb and three digits in each hindlimb. Forelimbs are used in burrowing and hindlimbs are used in leaping during locomotion.

SKIN

The skin of Cavia is made up of two layers—*epidermis* and *dermis* (Fig. 9.3).

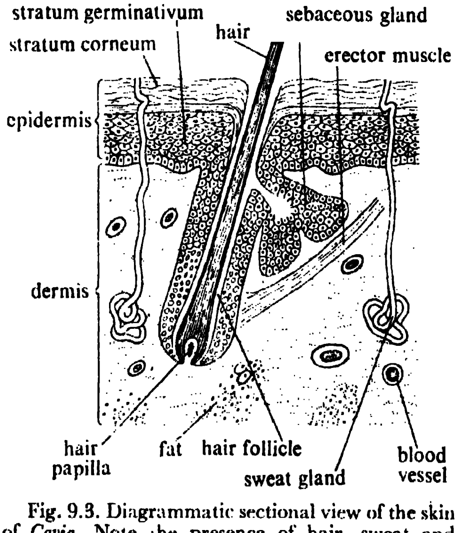


Fig. 9.3. Diagrammatic sectional view of the skin of *Cavia*. Note the presence of hair, sweat and sebaceous glands.

Epidermis is the outer layer and is ectodermal in origin while the inner dermis is mesodermal in origin. The epidermal part of the skin is made up of the following layers: **Stratum corneum.** It is the outer horny layer and is made up of dead cells. The horny texture is due mainly to the formation of a protein called keratin. **Transitional layer.** Beneath the stratum corneum, a layer called transitional layer is present. It is made up of flat cells and the cells are derived from the layer situated beneath it. **Stratum germinativum.** The innermost layer of the epidermis is known as stratum germinativum or Malpighian layer. The cells of this layer are polyhedral in appearance and contain conspicuous nucleus and granules. These cells divide mitotically to form the upper layers.

The dermis is made up of loose connective tissue, blood vessels and nerves. In the dermis the following structures are present: **Hair follicle.** Epidermis penetrates into the dermis and forms small pocket called hair follicle. Hair papilla is located in the inner end of the follicle and the hair emerges from the papilla. Smooth muscles called *erector muscles* are associated with the papilla. These muscles raise the hair. **Sebaceous gland.** These are flask-shaped glands and they open into the hair papilla. The secretion of these glands is oily in nature and the name of the secretion is *sebum*. Sebum keeps the hairs oily. **Sweat gland.** These are much coiled tube-like glands. The glands open to the outside through the epidermis. Secretion of these glands is known as *sweat*. Sweat is watery in nature. It helps in regulation of the body temperature and excretion.

COELOM

The body cavity or coelom of Cavia is transversely separated into two compartments by a muscular partition called *diaphragm*. The anterior compartment is known as thoracic cavity and it houses heart and lungs. The posterior cavity is known as abdominal cavity which contains stomach, liver, intestine, kidneys gonads, etc. The abdominal cavity is lined internally by *peritoneum* which becomes folded to form *mesenteries* to support the abdominal organs. The diaphragm is convex at its anterior surface and concave at its posterior surface.

SKELETAL STRUCTURES

Exoskeleton

Cavia possesses well-developed exoskeletal structures in the form of hairs and claws. The hairs cover the body and the claws are present at the digital tips. As already described, hair develops in hair-follicle. Each hair is a slender rod-like structure having a central core (*pith*) and an outer solid layer (*cortex*). The claws are typically reptilian in construction.

Endoskeleton

The entire internal skeleton of Cavia except certain parts of nose and ear is fully ossified. Cartilage is present at the tip of certain bones. The skeletal system is divided into (1) Axial and (2) Appendicular skeletons.

Axial skeleton. The axial skeleton includes the (1) skull, (2) vertebral column, (3) sternum and (4) ribs.

SKULL. Three firmly united parts constitute the skull. These parts are: (a) cranium, (b) sense capsules and (c) visceral skeleton.

Cranium. Cranium or the brain box is made up of several well-defined skeletal pieces. These pieces are united with each other and distinct sutures are present between these pieces. The skeletal pieces that make up the cranium are: (*i*) *Occipital bones.* There are four occipital bones. These bones encircle the *foramen magnum.* The *supraoccipital* bone is located at the top and below it lies the *basioccipital.* There are two *exoccipital* bones located one on each lateral side. Each exoccipital is drawn back as pointed and curved *paroccipital process.* (*ii*) *Occipital condyle.* There are two occipital condyles (Fig. 9.4B) located one on either side of the foramen magnum. The condyles act as articulators between the skull and first vertebra. (*iii*) *Parietal bones.* Anterior to the supraoccipital there are two parietal bones forming the roof of the cranium. (*iv*) *Frontal bones.* The anteriormost portion of the roof of the cranium is formed by a pair of frontal bones (Fig. 9.4A). The outer border of each frontal bone is concave. The dorsal wall of the orbit is formed by it. (*v*) *Sphenoid bones.* Two sphenoid bones called *basisphenoid* and *presphenoid* form the floor of the cranium. The lateral walls of the cranium is formed by *alisphenoid* and *orbitosphenoid* (Fig. 9.5). (*vi*) *Squamosal.* Two squamosals, one on either side of the lateral wall of cranium are present. The squamosals take part in the formation of *zygomatic arch.* (*vii*) *Cribriform plate.* The inner anterior wall of the cranium is formed by a *cribriform plate.* The plate is perforated and separates the cranium from the olfactory capsule.

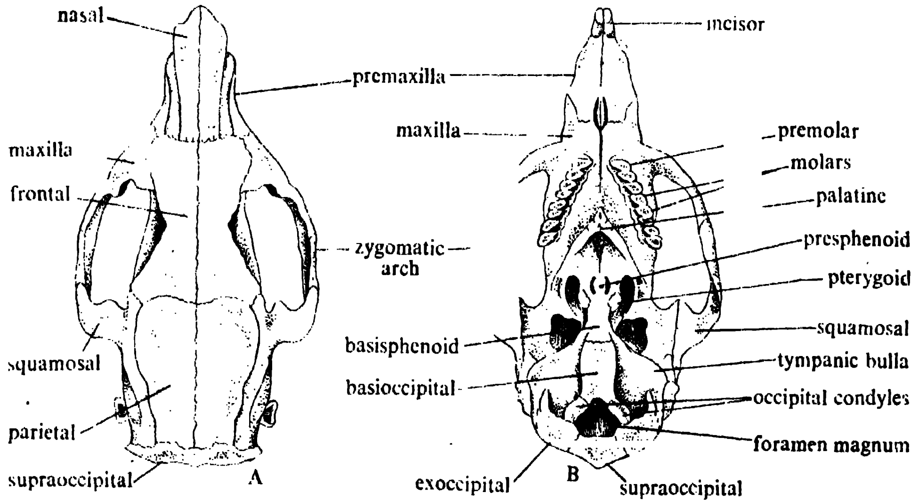


Fig. 9.4. Skull of *Cavia.* (A) Dorsal view. (B) Ventral view.

Sense capsules. Three different sense capsules are present in the skull. The capsules are paired and house eyes, ears and nostrils. Architecture of the sense capsules are discussed below: (*i*) *Olfactory capsule.* The roof of the olfactory capsule is formed by a pair

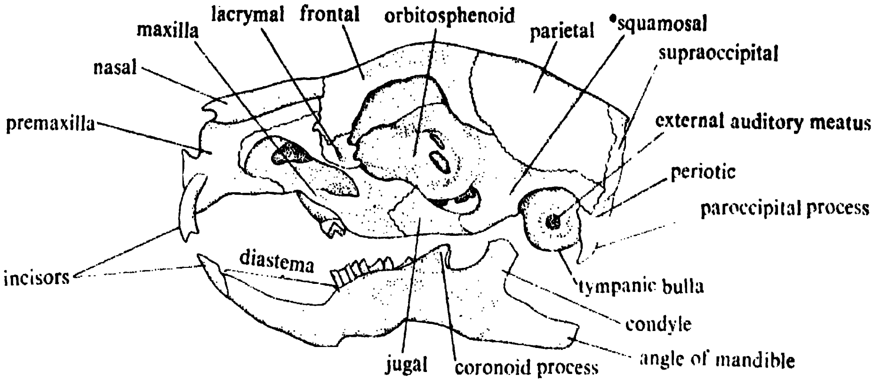


Fig. 9.5. Lateral view of skull and lower jaw of *Cavia*.

of *nasals*. The posterior lateral wall of the capsule is made up of *maxilla* and the anterior lateral wall is formed by *premaxilla*. Both maxilla and premaxilla are parts of the visceral skeleton. A *vomer* is present along the midventral line and posteriorly it articulates with the presphenoid. The two nasal cavities are separated from each other by a vertically placed cartilaginous plate called *mesethmoid*. As supporting structures for the olfactory epithelium there are small and spongy bones called *turbinals* present inside the nasal cavity. (*ii*) *Optic capsule*. The anterior wall of the capsule is formed by a small bone called *lachrymal*. It is perforated by a small *lachrymal foramen*. The ventral wall of the orbit is formed by the *Zygomatic arch*. The maxilla, jugal and squamosal bones take part in the formation of the arch. An *interorbital septum* forming the inner wall as a partition between the two orbits is present. The upper part of the septum is formed by *orbitosphenoid* and the lower part is formed by *presphenoid*. (*iii*) *Otic capsule*. Covering the membranous labyrinth, a bone called *periotic bone* is present. The shape of the bone is irregular and is formed by the fusion of three small bones. A *tympanic bone* remains firmly attached with the outer surface of the periotic. The tympanic bone is flask-shaped and base of the flask is called *tympanic bulla* while the neck is called *external auditory meatus*. Three small bones *malleus*; *incus* and *stapes* are jointly known as *auditory* or *ear ossicles*. These are housed inside the tympanic bulla.

Visceral skeleton. The first and second pair of visceral arches become modified to form the upper jaw, lower jaw and also help in the articulation of the jaw with the skull. Each half of the upper jaw is composed of three pieces of bones. They are *premaxilla*, *maxilla* and *jugal*. Teeth are borne by the premaxilla and maxilla. The roof of the mouth cavity is known as *palate*. The palate is formed by the inward projection of premaxilla, maxilla, a pair of *palatines* and a pair of *pterygoids*.

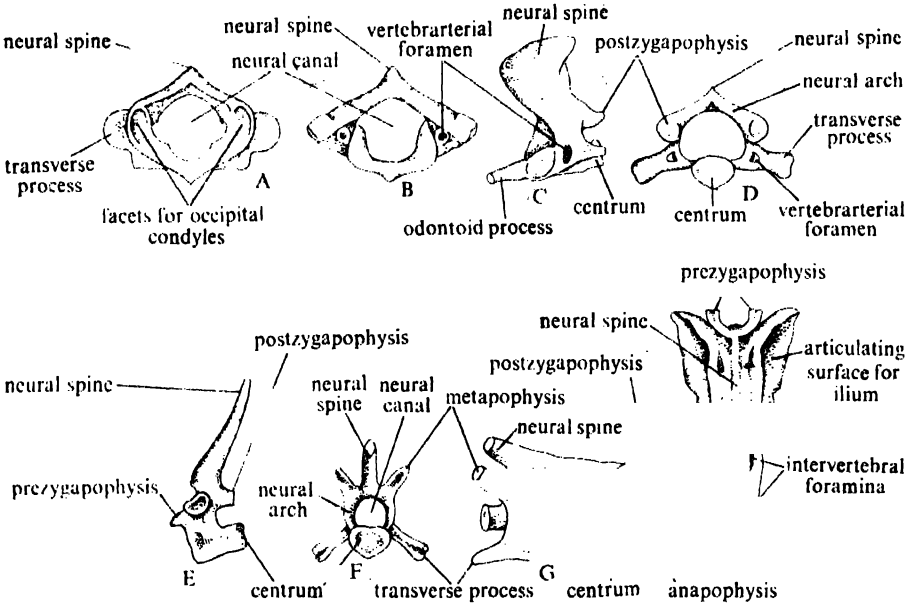
The lower jaw or *mandible* is made up of two incompletely united halves. Each half of the mandible is composed of a single piece of bone called *dentary* (Fig. 9.5). Teeth are present on the jaw bone. The posterior broad part of the mandible is provided with three projections called *coronoid*, *condylar* and *angular* processes. The mandible is articulated with the squamosal of the upper jaw at the posterior region of the zygomatic arch.

The base of the tongue is supported by a small bone called *hyoid bone*. The hyoid consists of a median body and two pairs of projections or *cornua*. Anterior cornua are connected to the periotics and the posterior cornua are connected to the larynx.

VERTEBRAL COLUMN. The vertebral column is made up of 37 vertebrae arranged in a linear fashion. The vertebrae are divisible into five distinct types. They are: (*a*) Cervical, (*b*) Thoracic, (*c*) Lumbar, (*d*) Sacral and (*e*) Caudal. A cartilaginous pad called *intervertebral disc* is present between the successive vertebrae.

Peculiarities of a typical vertebra. A typical vertebra is build upon the same plan as in other vertebrates. The specialised features are: (*i*) Centrum is acoelous, that is flat in both surfaces. (2) Neural arch is with distinct upper *lamina* and lower *pedicel*. The pedicel is notched to form the *intervertebral foramen* through which emerges the spinal nerve. (3) Pre- and postzygapophysis are mounted on specially developed *metapophysis* and *anapophysis*.

Cervical vertebrae. Cervical vertebrae are seven in number. In general, all the cervical vertebrae are with small centrum and short neural spine. (Fig. 9.6D). The base of the transverse process is perforated by a *vertebrarterial foramen* through which the carotid artery passes. The first cervical vertebra is known as *atlas* (Fig. 9.6A, B). It is ring-like and its centrum is insignificant. It's neural spine is very small and the transverse process is small and flat. The zygapophyses are absent. The anterior surface is provided with a pair of facets for receiving the occipital condyles (Fig. 9.6A). The neural canal is divided horizontally by a fibrous ligament. The second cervical vertebra is known as *axis*. The centrum of the axis is broad and drawn anteriorly into a peg-like *odontoid process* (Fig. 9.6C). It's neural spine is compressed and the spine extends anteroposteriorly. The transverse processes are small with perforated base.


neural spine
neural spine
neural canal
vertebrarterial foramen
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postzygapophysis
neural spine
neural arch
transverse process
transverse process
A
B
C
D
facets for occipital condyles
odontoid process
centrum
centrum
vertebrarterial foramen
prezygapophysis
neural spine
postzygapophysis
articulating surface for ilium
postzygapophysis
neural spine
neural spine
neural canal
metapophysis
neural spine
prezygapophysis
neural arch
intervertebral foramina
E
F
G
centrum
transverse process
centrum
anapophysis

Fig. 9.6. Different vertebrae of *Cavia*. Anterior (A) and posterior (B) views of Atlas. C. Lateral view of Axis. D. Anterior view of a typical cervical vertebra. E. Side view of a thoracic vertebra. Anterior view (F) and lateral view (G) of a lumbar vertebra. H. Dorsal view of sacrum.

Thoracic vertebrae. Thoracic vertebrae are twelve in number and have been grouped into two series—(*i*) Anterior thoracic and (*ii*) Posterior thoracic vertebrae

Anterior thoracic vertebrae. The first nine thoracic vertebrae are called anterior thoracic vertebrae. These vertebrae are provided with small and compact centrum and concave facets on the sides for the articulation of the head or *capitulum* of the rib. The neural spine of the vertebra is elongated, narrow and directed backward. The transverse process is strongly built and bears a facet on the ventral surface for articulation with the head or *tuberculum* of rib (Fig. 9.6E). *Posterior thoracic vertebrae.* The last three thoracic vertebrae are called posterior thoracic vertebrae. The transverse process of these vertebrae is small and lack facets. The centrum has lateral facets for articulating the ribs. The neural spine is flat sidewise and directed forward.

Lumbar vertebrae. Lumbar vertebrae are seven in number. The vertebrae are large and the size increases from anterior to posterior end. The vertebrae are with well-developed zygapophyses, metapophysis and anapophysis (Fig. 9.6F, G). The neural spine is flat and directed anteriorly. The first and second lumbar vertebrae are provided with ventro-median ridges. The ridge is called *hypapophysis*. The muscles from the diaphragm rest on it. The transverse processes are large and expanded.

Sacral vertebrae. The four sacral vertebrae are fused and have formed the *sacrum* (Fig. 9.6H). The sacrum is placed between the two halves of the pelvic girdle in a compact fashion. The first sacral vertebra is the largest and the size decreases from anterior to posterior end. The neural spine of sacral vertebra is straight. It's transverse process is flat and laterally expanded. The zygapophysis is reduced, anapophysis is absent and metapophysis is much reduced.

Caudal vertebrae. Caudal vertebrae are seven in number and the size of the vertebrae decreases gradually from anterior to posterior end. There is a gradual reduction of the associated parts of the vertebrae and the last two vertebrae have nothing but rod-like centra.

STERNUM. Sternum is present in the mid-ventral line of the thorax as an elongated and narrow rod. It is segmented and each segment is known as *sternebra.* The first sternebra is the largest and it articulates with the ill-developed clavicles. All but the last sternebra are provided with articulating surfaces for the ribs. The last sternebra is called *xiphisternum.* The tip of the xiphisternum is provided with a cartilaginous plate called *xiphoid cartilage.*

RIBS. There are twelve pair of ribs. The first seven pair of ribs are extended between the vertebral column and sternum. They are called *true ribs.* The remaining five pair of ribs are either with indirect or without any connection with the sternum. They are called *false ribs.* A typical rib is made up of two parts a bony *vertebral part* and a short and cartilaginous *sternal* or *costal part.* The first nine ribs articulate with the vertebral column by two heads—the *capitulum* is articulated with the centrum and the *tuberculum* is articulated with the transverse process. The tuberculum is absent in the last three ribs and as such they cannot articulate with the transverse process.

Appendicular skeleton. The pectoral and pelvic girdles together with fore- and hind-limb bones make up the appendicular skeleton (Fig. 9.7).

PECTORAL GIRDLE. The pectoral girdle is small and no hard structure is present in between the two halves of the girdle. Ossification of the girdle is almost total. Each half of the girdle is made up of *scapula* and *clavicle.* The scapula is large and triangular in shape (Fig. 9.7B). It's apex is provided with *glenoid cavity* which articulates with the head of *humerus.* A small *coracoid process* is present in front of the glenoid cavity. *Suprascapula* is present as a strip of cartilage along the broad margin of the scapula. On the outer region of the scapula, there is a bony projection or *spine.* The spine extends as *acromian.* Acromian gives out a downward process called *metacromian.* The clavicle is slender, rod-like and reduced. It remains embedded within the muscles.

FORELIMBS. From proximal to distal end the forelimb is made up of *humerus, radius* and *ulna, carpals, metacarpals* and *phalanges* (Fig. 9.7A). The humerus is strongly built. The proximal end of the humerus is round and has formed the *head.* Greater and lesser *tuberosities* and *bicipital groove* are located at the proximal end. A *deltoid ridge* runs along the side of the humerus. The distal end of the humerus is provided with a pulley-like *trochlea.* The trochlea articulates with the radius and ulna. There are two depressions just above the trochlea. The depression located in front is called *coronoid fossa* and the one at the back is called *olecranon fossa.* A *supratrochlear foramen* runs between the depressions. Radius and ulna are two completely separated rod-like bones but the two lie close together. Radius is shorter than ulna and is located on the inner side. The proximal end of the ulna is provided with a *sigmoid notch* which fits with the trochlea of humerus. The tip of the ulna is extended backward as *olecranon process* which forms the elbow point. The distal ends of both radius and ulna are provided with articulating surfaces. The carpal bones are seven in number and they are arranged in two rows. The three proximal carpal bones of the first row are known as *radiale, intermedium* and *ulnare.* The distal row contains four small bones and a small *pisiform bone.* There are four metacarpal bones forming the palm region of the forelimb. There are four digits and each digit is made up of three *phalanges.* The terminal phalanx in each digit ends in claws.

PELVIC GIRDLE. The pelvic girdle is made up of two strongly built halves (Fig. 9.7 D_1), each half being known as *os innominatum.* Each half is composed of three bones —*ilium, ischium* and *pubis* (Fig. 9.7D_2). Symphysis or union between the two halves occurs at the region of pubis. The ilium and ischium remain free. The symphysis is called *pubic symphysis.* Ilium is long, blade-like and articulates with the sacrum along the side. Ischium is the posterior continuation of the ilium, and forms the posterior one third of the girdle. Pubis is small and curved. One end of it is united with the ilium and the other end is united with the ischium. It occupies the ventral position. A large gap called *obturator foramen* is present between pubis and ischium. A socket called *acetabulum* is present. It is formed by the contribution of both ischium and pubis.

HINDLIMB. The hindlimb is made up of the following bones along its proximal to distal axis. The bones are (*i*) *femur*, (*ii*) *tibia* and *fibula*, (*iii*) *tarsals*, (*iv*) *metatarsals* and (*v*) *phalanges* (Fig. 9·7C). Femur is a long and stout bone. The proximal end of the femur has become round to form the *head*. The head fits in the acetabulum of the pelvic girdle. Three elevated areas called *greater trochanter*, *lesser trochanter* and *third trochanter* are located near the head. Two round *condyles* mark the distal end of the femur. The condyles are separated from each other by a *patellar groove*. Tibia and fibula are long rod-like bones. They are united at their proximal

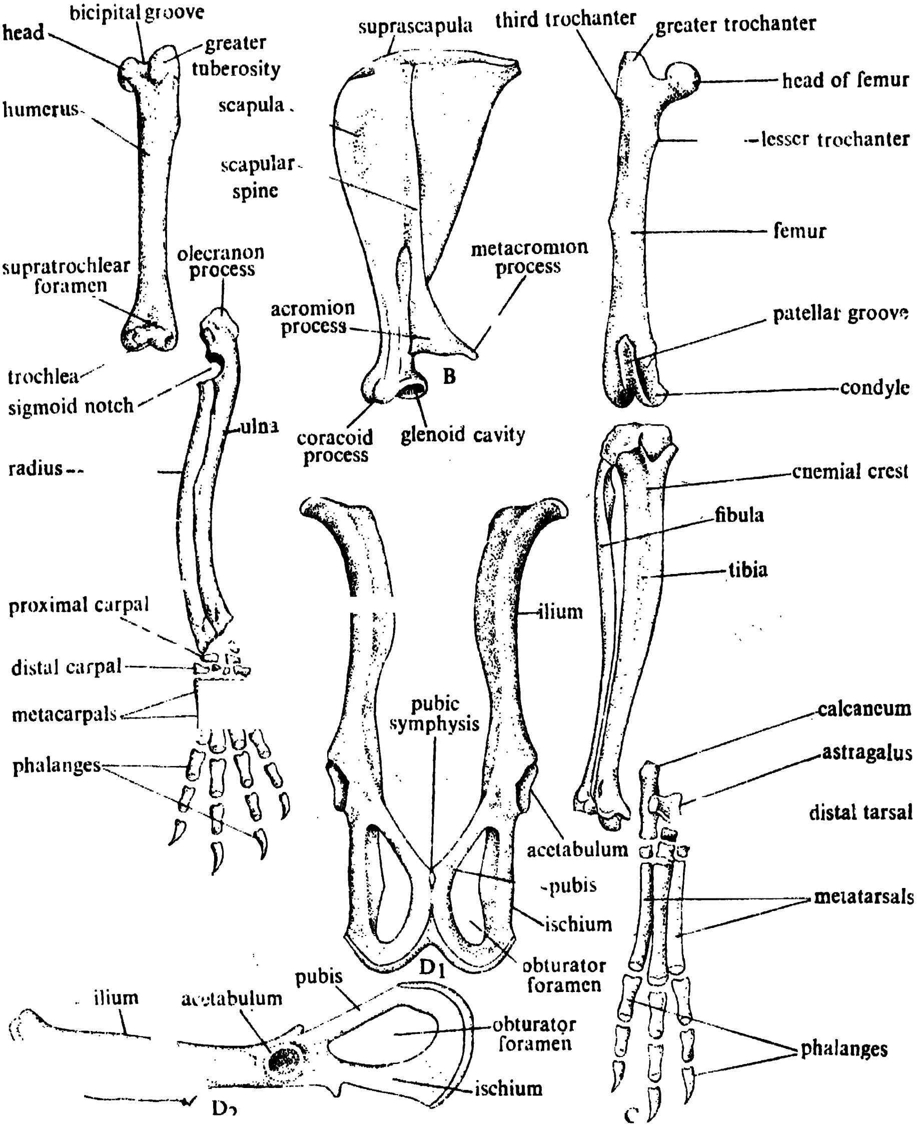
head
bicipital groove
greater tuberosity
humerus
supratrochlear foramen
olecranon process
trochlea
sigmoid notch
ulna
radius
proximal carpal
distal carpal
metacarpals
phalanges
suprascapula
scapula
scapular spine
acromion process
metacromion process
coracoid process
glenoid cavity
B
third trochanter
greater trochanter
head of femur
lesser trochanter
femur
patellar groove
condyle
cnemial crest
fibula
tibia
calcaneum
astragalus
distal tarsal
metatarsals
phalanges
C
ilium
pubic symphysis
acetabulum
pubis
ischium
obturator foramen
D1
ilium
acetabulum
pubis
obturator foramen
ischium
D2

Fig. 9.7. Appendicular skeleton of *Cavia*. A. Forelimb. B. Scapula (left half). C. Hindlimb. D_1. Ventral view of pelvic girdle. D_2. Side view of an *os innominatum*.

and distal tips but are separated in the middle. Tibia is strong and well developed and fibula is ill developed and thin. A ridge called *cnemial crest* is present on the tibia. Tarsals are six in number and they are arranged in three rows. The proximal row houses two bones called *astragalus* and *calcaneum*. In the middle row there is a single piece called *navicular*. The distal row houses three small *tarsal* bones. There are three long metatarsal bones forming the foot. Three digits are present in the hindlimb. Each digit is made up of three *phalanges*. The terminal phalanx is provided with claw.

DIGESTIVE SYSTEM

The digestive system is constituted by the *alimentary canal* and the *digestive glands* (Fig. 9·8). The basic plan on which the digestive system rests is same as in other vertebrates but individual variation is present.

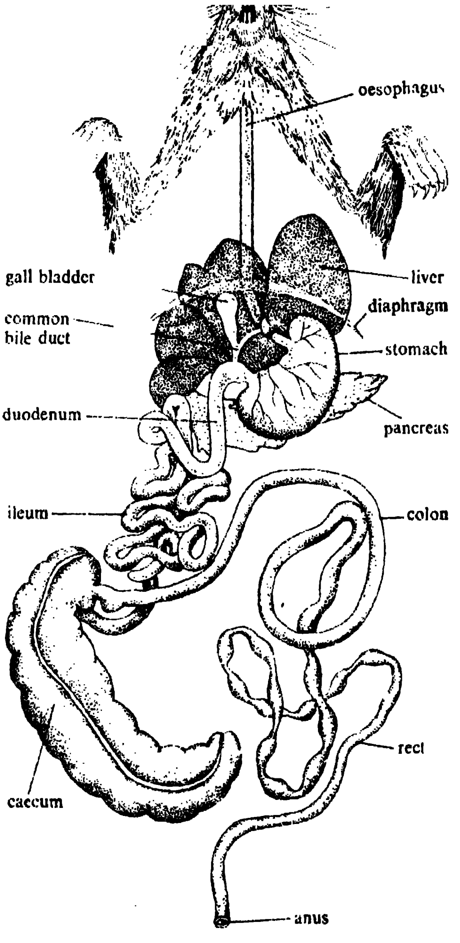

Fig. 9.8. Digestive system of *Cavia*.

Alimentary canal. It is a long tube starting from mouth to anus. But the tube is demarked into different regions. The function of each region is different. Discussion on the different regions of the alimentary canal is given below. **Mouth.** The alimentary canal begins from the mouth. It is a transverse aperture and is guarded by two soft and movable lips. The upper lip is provided with a cleft in the middle. **Buccal cavity.** Mouth leads to the buccal cavity. The roof of the buccal cavity is formed by a *palate*. The anterior portion of the palate is called *hard palate*. The supporting bones present at this portion make it hard. As no supporting bone is present, the posterior portion of the palate is soft and is known as *soft palate*. The palate separates the mouth cavity from the nasal passage. The floor of the buccal cavity houses the *tongue*. The anterior end of the tongue is free and the posterior end is attached with the floor. The tongue is muscular and movable. The upper surface of the tongue is rough and contains numerous papillae or *taste buds*. Both the jaws are provided with teeth. The teeth help in ingesting food. The teeth are *thecodont, heterodont* and *diphydont*. Dental formula is $\frac{1.0.1.3}{1.0.1.3}$. The incisors are long, chisel-shaped and can be seen from out side. Canines are absent and as a result a gap called *diastema* has appeared between the incisor and premolar. A tooth has two parts, *crown* and *root*. The crown is the visible part and the root remains embedded in a socket on the jaws. The tooth is made up of a substance called *dentine*. The dentine of the root region remains covered by *cement* while the crown region of the tooth remains covered by hard and shiny *enamel*. Each tooth bears an inner pulp cavity. This cavity remains filled up with jelly like pulp, blood vessels and nerves.

Pharynx. Buccal cavity leads to another chamber called *pharynx*. The dorsal part of the pharynx is called *naso-pharynx* and the ventral part is called *bucco-pharynx*. Paired *internal nostrils* and *eustachian tubes* enter into the naso-pharynx. The posterior margin of the soft palate extends into the naso-pharynx as *velum*. The two sides of the velum is provided with a peculiar lymphoid tissue called *tonsil*. A slit called *glottis* is present on the floor of the bucco-pharynx just posterior to the tongue. The glottis communicates with the respiratory tube and is guarded by a cartilaginous flap called *epiglottis*. Posteriorly the bucco-pharynx opens into the oesophagus through an aperture called *gullet*. **Oesophagus.** Oesophagus is a long tube running along the midventral line of the neck region. It runs through the thoracic region and after passing through the diaphragm opens into the stomach.

Stomach. Stomach is a highly muscular and glandular sac. The inner concave side of the stomach is called *lesser curvature* and the outer convex surface is called *greater curvature*. The end of the stomach towards the oesophagus is called the *cardiac end* and its opposite end is called *pyloric end*. Because of a twisting, the cardiac end has taken a position towards the left and pyloric end has taken a position towards the right in the abdominal cavity. The opening at the pyloric end is guarded by a valve called *pyloric sphincter*. **Intestine.** The remaining part of the alimentary canal is known as *intestine*. It is divisible into *duodenum*, *ileum* and *large intestine*. The duodenum begins from the pyloric end of the stomach and forms a 'U'-shaped loop. The ileum is a much coiled continuation of the duodenum. The coiled loops of the ileum are held in position by folds of *mesenteries*. The ileum opens into the large intestine and the opening is guarded by an iliocoelic valve. The large intestine is wide and is divisible into proximal *colon* and distal *rectum*. The colon is coiled and beaded in parts while the rectum is straight. A large blind sac called *caecum* is present at the point of opening of the ileum into the colon. **Anus.** The terminal part of the alimentary canal is represented by an aperture called *anus*. The anus is guarded by sphincter muscle.

Digestive glands. The different digestive glands that help the process of digestion are listed below.

Salivary glands. Four pair of salivary glands are present. *Parotid glands* are located near the angle of the mandible. *Submaxillary glands* are situated on the floor of the buccal cavity. *Sublingual* glands lie beneath the tongue and *Infraorbital* glands are located beneath the eye. All the glands have separate openings into the buccal cavity through ducts. The secretion of the salivary glands is known as *saliva*. Saliva helps in moistening food and contains an enzyme called *ptyalin*.

Liver. It is a massive gland located beneath the diaphragm and above the stomach. It is a five-lobed structure and remains attached to the diaphragm by falciform ligament. The secretion of the liver is *bile*. Bile is kept temporarily stored in a pyriform *gall bladder* lodged between 3rd and 4th lobe of the liver. A common bile duct formed by the union of hepatic duct (from liver) and cystic duct (from gall bladder) carries bile to the duodenum. **Pancreas.** It is a whitish, elongated and irregular shaped gland located between the limbs of the duodenum. The secretion of the pancreas is known as *pancreatic juice*. The juice is carried to the distal part of the duodenum by a *pancreatic duct*. **Gastric glands.** Innumerable gastric glands are present along the inner lining of the stomach. The juice produced by these glands is known as *gastric juice*. **Intestinal glands.** Numerous glands are present in the inner lining of the duodenum and intestine.

Mechanism of digestion. The mechanism of digestion may be divided into three steps. The steps are ingestion, digestion and egestion.

Ingestion. Young guineapigs live on the milk secreted from the mammary glands of the mother. They suck the glands to get the milk. Adults are vegetarian and herbivorous. The food is taken by the help of the teeth and chewed. **Digestion.** Digestion begins in the buccal cavity. The amylolytic enzyme, ptyalin present in the saliva breaks down starch into maltase. The masticated food inside the stomach comes into contact with the gastric juice containing *hydrochloric acid* in low concentration, *pepsin* and *renin*. HCl hydrolyses the food and the enzyme pepsin converts protein into *peptone*. The enzyme renin coagulates the protein of the milk. The partially digested food within the stomach is known at this stage as *acid chyme*. It passes slowly into the duodenum. The flow is regulated by the pyloric sphincter. Within the duodenum the chyme comes in contact with bile and pancreatic juice. The bile and pancreatic juice being alkaline in nature neutralise the acidity of the chyme. The chyme then passes to the intestine and becomes subjected to the secretion of the intestinal glands. The intestinal glands secrete *trypsin*, *erepsin* and *lipase*. They convert peptones into amino acids. The enzyme lipase breaks the fats of the food into *fatty acid* and *glycerol*. Another enzyme *amylase* converts starch into glucose. Thus the final products are the amino acids, fatty acid, glycerol and glucose. They are taken into the blood stream from the lining of the small intestine. Water is absorbed from the large intestine. **Egestion.** After water being absorbed, the residual matter is kept stored temporarily in the rectum. Finally, the stored matter called faeces is voided through the anus in the form of small pellets. The faecal pellets passed in day time are dry and hard but those passed at night are soft with mucus. The guineapigs are in the habit of taking the soft nocturnal faeces (coprophagy).

Spleen

It is an elongated brown coloured organ. It is morphologically connected with the alimentary canal, being situated on the dorsal side of stomach by a fold of mesentery. Spleen is devoid of any duct, and does not produce any hormone. It is believed that it destroys old red blood corpuscles.

RESPIRATORY SYSTEM

Respiration in Cavia is aerial. Lungs are the site where gaseous exchange occurs. The air from the environment passes through a long tract before entering the lungs. Following are the different regions of the respiratory tract: (*i*) **External nares.** These are paired openings situated at the tip of the snout. (*ii*) **Nasal cavities.** These are paired cavities separated from each other by a nasal septum. (*iii*) **Internal nares.** These are paired openings of the nasal cavities. (*iv*) **Naso-pharynx.** It is the part of the pharynx where the internal nares open. (*v*) **Glottis.** It is an aperture on the floor of the buccal cavity. A cartilaginous flap called *epiglottis* forms a cover over the glottis. (*vi*) **Larynx.** It is a chamber, formed by four cartilages. A *thyroid cartilage* (Fig. 9.9) forms the ventral and lateral sides. A pair of small *arytenoid cartilages* form the dorsal wall and a circular *cricoid cartilage* forms the posterior part. The cavity of the larynx bears a pair of elastic bands called *vocal cords*. The vocal cords are kept separated by a narrow *rima glottis*. Sound production is done with the help of the vocal cords. (*vii*) **Trachea.** It is a long tube. It emerges from the larynx and runs midventrally through the neck. It is encircled by series of transverse cartilaginous rings. The rings are incomplete on the dorsal side. (*viii*) **Bronchus.** The trachea after entering into the thorax bifurcates into two branches forming the right and left *bronchi*. Each bronchus enters into the lung of the corresponding side and breaks up into finer *bronchioles*. (*ix*) **Lungs.** The lungs are housed in the thoracic cavity. They are spongy and elastic. Each lung is enclosed by a two-layered pleural sheath. The left lung is three lobed. An additional lobe called *azygos lobe* is present in the right lung. The outer layer of the pleural sheath is called *parietal pleura* and the inner layer is called *visceral pleura*. The two layers of the pleura are united at the apex of the lungs. The bronchioles, within the lungs, break up to form finer ducts called *alveolar ducts*. The wall of the alveolar ducts forms *alveolus*. The pulmonary blood vessels form network on the wall of the alveoli,

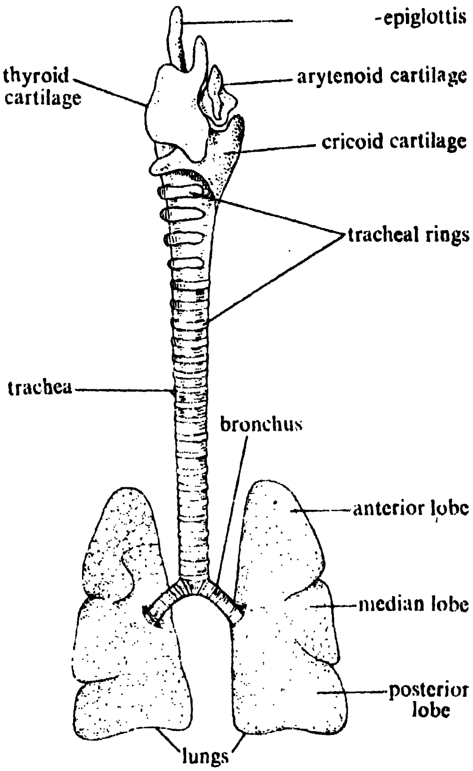

Fig. 9.9. Respiratory system of *Cavia*.

Mechanism of respiration. Gaseous exchange takes place on the surface of the lungs. The entire process of physical respiration may be resolved into **Inspiration** and **Expiration.** In inspiration the intercostal muscles contract to raise the ribs. This act increases the thoracic cavity. The diaphragm at the same time flattens to increase the chest cavity antero-posteriorly. Increase of thoracic cavity permits the lungs to expand. By expanding the lungs the air from outside is drawn in. The air from outside rushes through the respiratory tract and the air ultimately reaches the alveoli for aerating blood. In expiration, the retraction of intercostal muscles and diaphragm brings the thoracic cage back to its normal state and thus exerts pressure on the lungs. This pressure drives the air from lungs to the outside. Some air called residual air always remains captive inside the lungs.

CIRCULATORY SYSTEM

Two distinct circulatory fluids, namely, blood and lymph circulate through the circulatory system of the body. Blood flows through well defined blood vessels and is pumped by an organ called heart. The lymph flows through lymph vessels and intercellular spaces. Several contractile lymph hearts force the flow of lymph. The *blood vascular system* is formed by (*a*) blood, (*b*) heart and (*c*) blood vessels while the (*a*) lymph (*b*) lymph vessels and (*c*) lymph hearts constitute the *lymphatic system.*

Blood vascular system

Blood. Blood consists of liquid *plasma* and many *corpuscles* floating in the plasma. The plasma is a pale yellow fluid and contains various inorganic salts, vitamins and hormones. There are three different types of blood corpuscles. They are *erythrocytes, leucocytes* and *thrombocytes. Erythrocytes* or *red blood corpuscles or R.B.C.* are round and biconcave. Mature erythrocytes are nonnucleated and contain a red pigment called *haemoglobin.* Haemoglobin renders red colour to the blood. It has a strong but loose affinity for oxygen. The red blood cells carry oxygen from lungs to different parts of the body and carry back carbondioxide from different parts of the body to the lungs. *Leucocytes or white blood corpuscles or W.B.C.* are larger than R.B.C. and their number is much less than R.B.C. The leucocytes are of different types and their classification is dependent upon the structure of nucleus and stainability of the cytoplasmic granules. These cells move in amoeboid fashion and act as scavengers of the body. *Thrombocytes or blood-platelets* are small and nonnucleated. They occur in groups. In case of injury these cells break

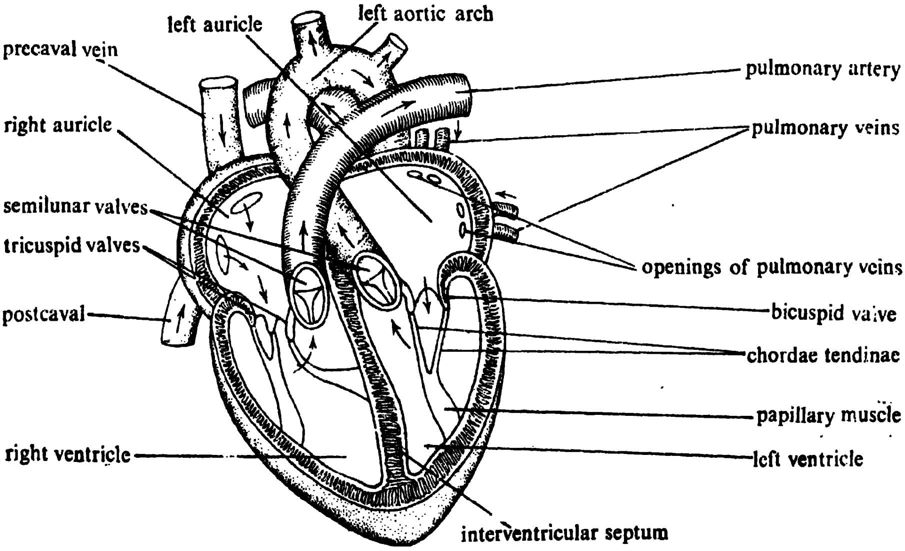

Fig. 9.10. Schematic sectional (longitudinal) view of the heart and the associated blood vessels of *Cavia.* Note the emergence of left aortic and pulmonary arches from the left and right ventricular cavities respectively.

down and produce an enzyme which coagulates the blood and thereby prevents loss of blood.

Heart. The heart is located in a space within the thorax between the two pleural bags. The space is known as *mediastinum*. The heart is triangular in shape and is covered over by a thin peritoneal membrane called *pericardium*. The apex of the heart occupies a position slightly towards the left of the thoracic cavity. The heart is four chambered being formed by two *auricles* and two *ventricles* (Fig. 9.10). *Sinus venosus* is absent. The auricles are thin walled and a partition called *interauricular septum* is present between the left and right auricles. The interauricular septum bears a small depression in the middle. The depression is called *fossa ovalis*. During embryonic stage an aperture called *foramen ovale* remains present at the region of fossa ovalis. This aperture, however, becomes closed before the birth of the animal. The ventricles are thick walled. A partition called *interventricular septum* is present between the right and left ventricles. The left ventricle is larger and more muscular than the right ventricle. The inner wall of the ventricles is provided with muscular ridges called *columnae carnae*. Strands of muscles called *chordae tendinae* are present between the flaps of the ventricular valves and the inner wall of the ventricle.

The right auricle receives deoxygenated blood from the right precaval vein (or right superior vena cava), the post caval vein (or inferior vena cava) and from the coronary vein (which drains blood from the muscles of the heart). These three openings are separate. The right auricle pours blood into the right ventricle through the *auriculoventricular orifice*. The aperture is guarded by a *tricuspid valve*. Three membranous flaps formed by the duplication of the inner lining membrane of the heart form the valve. The flaps remain attached to the wall of the ventricle through strands of muscles. The valve prevents the back flow of blood from ventricle to auricle. The pulmonary arch arises from the right ventricle, and the opening of the arch is guarded by three *semilunar valves*.

The left auricle receives oxygenated blood from the pulmonary veins through four separate apertures. The left auricle opens into the left ventricle. The left auriculoventricular aperture is guarded by a *bicuspid* or *mitral valve*. The biscuspid valve has two flaps and is formed in the same way as those of tricuspid valve. The chordae tendinae are also associated with the flaps. The arch of the aorta arises from the left ventricle and the aperture between the two is guarded by three semilunar valves.

Mechanism of circulation through heart. The heart works day and night by alternate contraction (systole) and relaxation (diastole). The two auricles begin their systole at the same time and blood from both the auricles is forced into both the ventricles. Deoxygenated blood goes to the right ventricle and oxygenated blood comes to the left ventricle. The back flow of blood is prevented by the auriculoventricular valves. The ventricles thus filled up with blood start systole. In this phase the auriculoventricular valves become closed and blood from the right ventricle is forced through the pulmonary arch while that from the left ventricle is forced through the left aortic arch. The ventricular systole is followed by a phase of diastole of the whole heart. At this stage the semilunar valves remain closed, deoxygenated blood from the caval veins enters the right auricle and oxygenated blood from pulmonary veins enters the left auricle.

Blood vessels. Blood is conveyed from the heart to the different parts of the body through well developed blood vessels. These vessels form a well-knit circuit inside the body. This type of circulation is known as closed circulation. Oxygenated blood is carried away from the heart by *arteries* (excepting pulmonary artery) and deoxygenated blood is carried to the heart by *veins* (excepting pulmonary vein). The arteries break up into arterioles which in turn break up into arterial capillaries. The arterial capillaries unite with venous capillaries and make up a capillary net work. The venous capillaries unite and form venules. The venules form the veins and thus a close circuit is built.

Arterial system

Two main arches come out from the heart. These are *pulmonary* and *aortic arches* (Fig. 9.11). Pulmonary arch emerges from the right ventricle and the left aortic arch emerges from the left ventricle. Semilunar valves are present at the base of each of the openings.

The pulmonary arch carries deoxygenated blood. Soon after its emergence from the right ventricle it bifurcates into two branches. One branch goes to the left lung and the other branch enters the right lung.

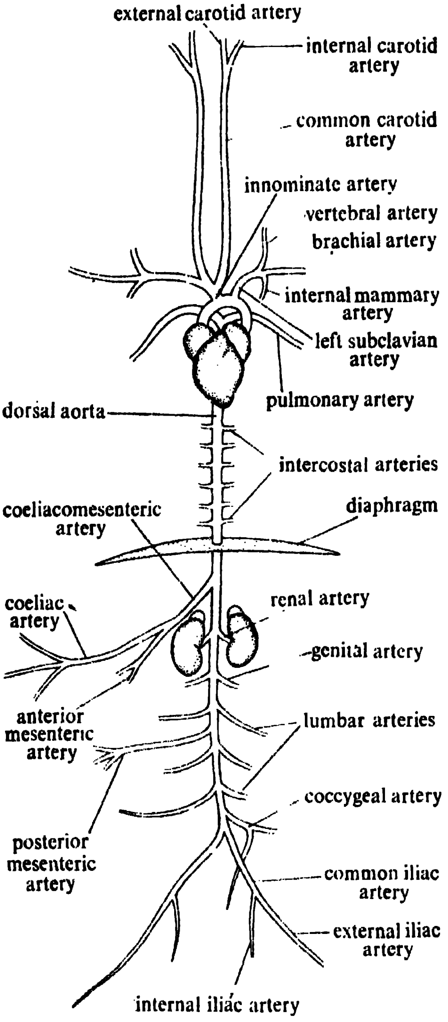
external carotid artery
internal carotid artery
common carotid artery
innominate artery
vertebral artery
brachial artery
internal mammary artery
left subclavian artery
pulmonary artery
dorsal aorta
intercostal arteries
coeliacomesenteric artery
diaphragm
coeliac artery
renal artery
genital artery
anterior mesenteric artery
lumbar arteries
coccygeal artery
posterior mesenteric artery
common iliac artery
external iliac artery
internal iliac artery

Fig. 9.11. Arterial system of *Cavia*.

Aortic arch. The left aortic arch is only present. After emerging from the left ventricle this aortic arch turns to left anterior to the heart and curves down posteriorly to take up dorsal position. This part of the aortic arch behind the heart is known as *dorsal aorta*. The branches that are given out by the left aorta and dorsal aorta are the following: *Coronary artery*. One pair of coronary arteries originate from the base of aortic arch. It supplies blood to cardiac tissue. *Innominate artery*. It is a short but stout artery and originates from the middle of the arch. It gives off three branches. These branches are: a pair of *carotids* and *right subclavian*. The subclavian comes out first. It gives off the following branches—(*i*) *Brachial artery* supplying the right forelimb, (*ii*) *Internal mammary artery* supplying ventral body wall and (*iii*) *Vertebral artery* supplying the vertebral column. The two carotid arteries run anteriorly along the lateral sides of the neck. Each artery breaks up near the head region into *internal carotid* and *external carotid arteries*. External carotid supplies blood to the external parts of head and internal carotid supplies blood to the brain.

Left subclavian artery. The left subclavian arises from the curved point of the arch. Likewise the right subclavian, it gives off three branches which supply blood to the similar organs of the right side. *Intercostal arteries*. Five or six pairs of intercostal arteries emerge out from the dorsal aorta to supply blood to the wall of the thorax and intercostal muscles of the ribs. *Phrenic arteries*. A pair of phrenic arteries is given out from the dorsal aorta. These arteries supply blood to the diaphragm. *Coeliacomesenteric artery*. A stout unpaired artery emerges from the abdominal part of the dorsal aorta. It soon divides into *coeliac* and *anterior mesenteric* branches. Coeliac supplies blood to stomach, spleen and liver and the anterior mesenteric branch supplies blood to duodenum, ileum and mesenteric folds. *Renal arteries*. A pair of renal arteries arises from the dorsal aorta and supply blood to the kidneys. *Genital arteries*. A pair of genital arteries originates from the dorsal aorta and supply blood to the gonads. *Lumbar arteries*. Four pairs of lumbar arteries come out from the dorsal aorta and supply blood to the dorsal side of the abdominal body wall. *Posterior mesenteric artery*. A median posterior mesenteric artery is located between the 1st and 2nd lumbar arteries. It supplies blood to the large intestine and posterior mesenteries. *Coccygeal artery*. A slender and unpaired branch comes out from the point of bifurcation of the dorsal aorta and supplies blood to the sacral and coccygeal regions of the vertebral column.

At the posteriormost end of the abdominal cavity, the dorsal aorta bifurcates to form the left and right *iliac arteries*. Each iliac artery again bifurcates into *external iliac* and *internal iliac*. The internal iliac supplies blood to ventral body wall and posterior part of urinary and genital systems. The (*viii*) Cerebellum is enlarged, folded and divided into a median *vermis* and two lateral lobes. Each lateral lobe is with a short *flocculus*. A broad band called *pons varolii* is present on the ventral side of the cerebellum.

(*ix*) Medulla oblongata is prominent and carries a vascularised *posterior choroid plexus* on its non-nervous roof.

Spinal cord. The spinal cord is the continuation of the brain which runs up to the posteriormost end through the neural canal of vertebral column. Posteriorly the spinal cord forms a narrow, triangular cone, called *conus terminalis*, from which bunch of nerves arise. These are called *filum terminale*. In the brachial and lumbar regions, the spinal cord is slightly swollen.

Peripheral nervous system

It includes nerves which are given out from brain and spinal cord. The nerves from the brain are called *cranial nerves* and those from the spinal cord are called *spinal nerves*.

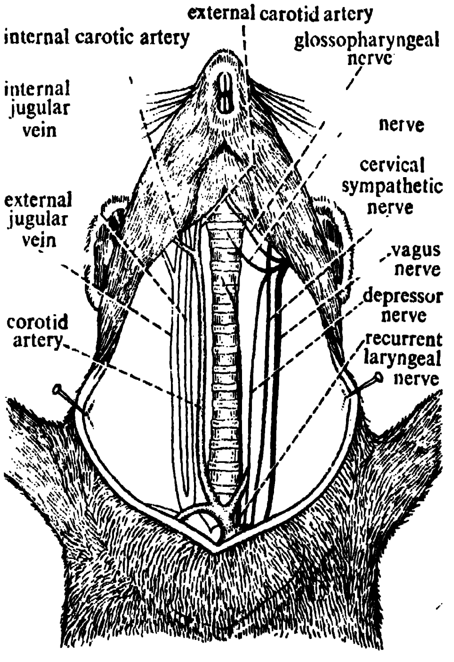
external carotid artery
internal carotic artery
glossopharyngeal nerve
internal jugular vein
nerve
cervical sympathetic nerve
external jugular vein
vagus nerve
depressor nerve
corotid artery
recurrent laryngeal nerve

Fig. 9.14. Dissection of the neck region in *Cavia*, showing the distribution of the main neck nerves (left side) and main blood vessels (right side).

Twelve pairs of cranial nerves are present. The origin and distribution of the cranial nerves in Cavia are basically similar to the cranial nerves of *Bufo* and *Calotes* already described (*vide* pages 212–213 and 254–255).

The tenth or vagus nerve after forming the vagus ganglion sends a branch called *cardiac depressor* to the heart, and a branch *anterior laryngeal* to the larynx. The main trunk runs posteriorly through the neck region (Fig. 9.14). Near thorax, the main trunk sends a branch called *recurrent laryngeal*, which in the left side curves around aorta and around subclavian in the right side, and finally turns anteriorly to supply the larynx. After entering the thoracic cavity, vagus sends usual branches to lungs, heart and other visceral organs. Figs. 9.15 and 9.16 show the origin and distribution of the fifth and seventh; nineth and tenth cranial nerves of Cavia respectively.

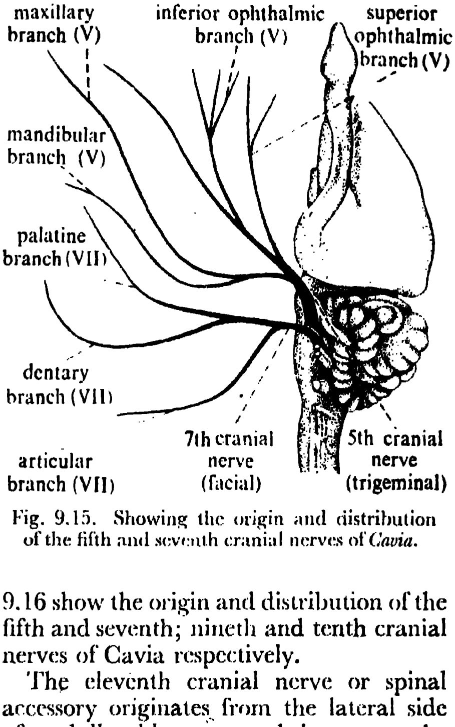
maxillary branch (V)
inferior ophthalmic branch (V)
superior ophthalmic branch (V)
mandibular branch (V)
palatine branch (VII)
dentary branch (VII)
7th cranial nerve (facial)
5th cranial nerve (trigeminal)
articular branch (VII)

Fig. 9.15. Showing the origin and distribution of the fifth and seventh cranial nerves of *Cavia*.

The eleventh cranial nerve or spinal accessory originates from the lateral side of medulla oblongata and innervates the muscles of neck region. A branch of it called *ramus internus* supplies nerves to the muscles of pharynx and larynx. This is a motor nerve. The twelfth cranial nerve or hypoglossal begins from the midventral region of the medulla oblongata and innervates the tongue muscles through a number of branches. This is a motor nerve.

Thirty two pairs of spinal nerves are built up in the same plan as that of toad. On each side, the fourth and fifth spinal nerves of the cervical region unite as *phrenic nerve* to supply the muscles of the diaphragm. The *brachial plexus* is formed by the participation of first four nerves in the cervical region and first thoracic nerve. It innervates the forelimbs. Hindlimb is innervated by *sciatic plexus*, which is formed by last two lumbar nerves and sacral nerves.

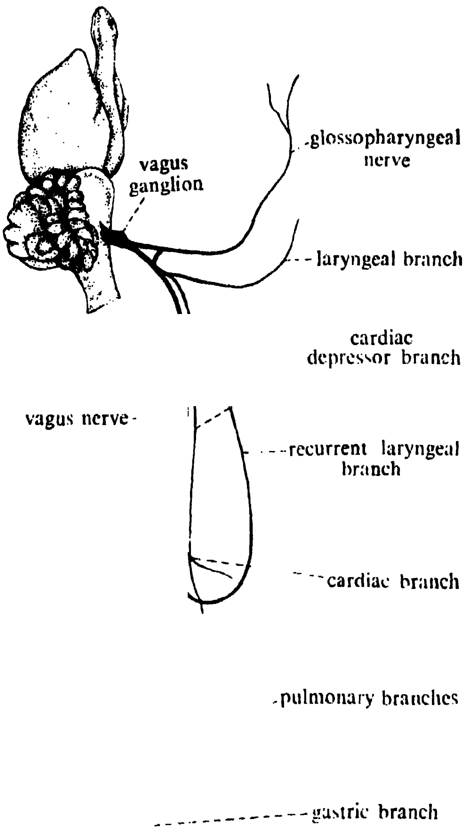
glossopharyngeal nerve
vagus ganglion
laryngeal branch
cardiac depressor branch
vagus nerve
recurrent laryngeal branch
cardiac branch
pulmonary branches
gastric branch

Fig. 9.16. Showing the origin and distribution of ninth and tenth cranial nerves of *Cavia*.

Autonomic nervous system

It is built up in the same amphibian plan and consists of a pair of sympathetic nerve cords, one on each side of the aorta. Each cord bears one *anterior* and one *posterior cervical ganglia*.

SENSE ORGANS

To receive different types of stimuli, there are different categories of receptors. The stimuli in the form of *touch*, *pain* and *temperature* are received by numerous *free nerve endings* or *encapsulated corpuscles* which remain scattered within the superficial layer of the skin. Taste is determined by group of specialised cells which remain within the papillae on the surface of the tongue. These sensory papillae are called *taste buds*. Smell is perceived by specially sensory olfactory cells which are distributed in the mucous membrane of nasal cavity. Eyes and ears are much specialised receptor organs for receiving stimuli in the form of light and sound respectively. Ears, in addition to hearing, are also responsible for maintaining balance.

Eyes. Eyes are built up in typical vertebrate plan (Fig. 9.17). The upper and lower eyelids are provided with hairs called *eye lashes*. Special features in the eyes of Guineapig are: (1) Presence of lacrymal gland on the upper side of each eye ball. It secertes a fluid called *tear* which cleans and lubricates the surface of the eye. (2) Lens is biconvex and focussing is done by changing the curvature of lens through the ciliary muscles. (3) Retina possesses both rod and cone cells. The former determines the intensity of light while the latter function to adjudge colours. Fig. 9.18 gives an idea of the microscopic structures of retina.

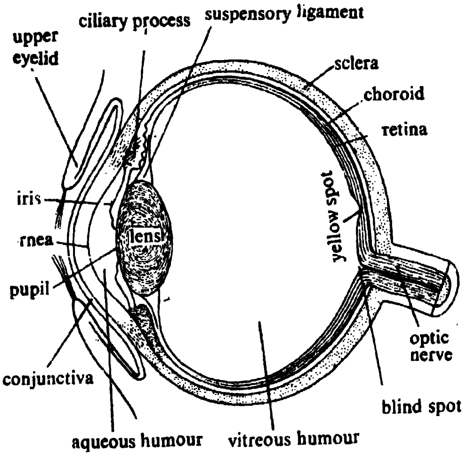
ciliary process
suspensory ligament
upper eyelid
sclera
choroid
retina
yellow spot
iris
rnea
lens
pupil
optic nerve
conjunctiva
blind spot
aqueous humour
vitreous humour

Fig. 9.17. Sectional view of eye of *Cavia*.

Ear. Each ear is divisible into (*a*) external ear, (*b*) middle ear and (*c*) internal ear (Fig. 9.19).

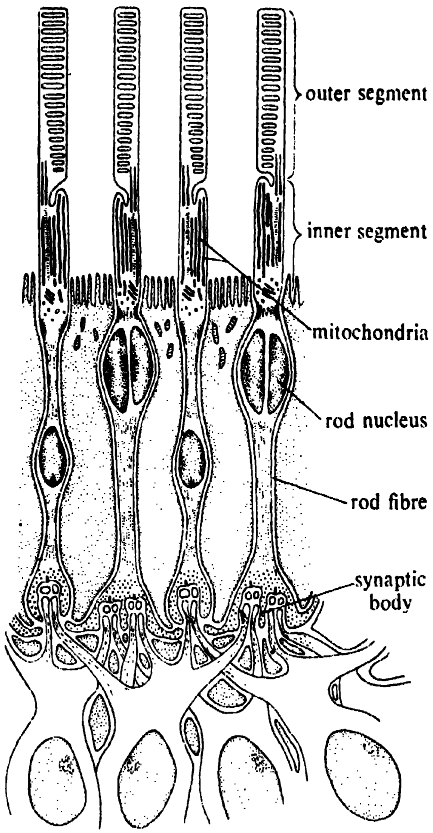
outer segment
inner segment
mitochondria
rod nucleus
rod fibre
synaptic body

Fig. 9.18. Microscopic structure of retina of *Cavia*.

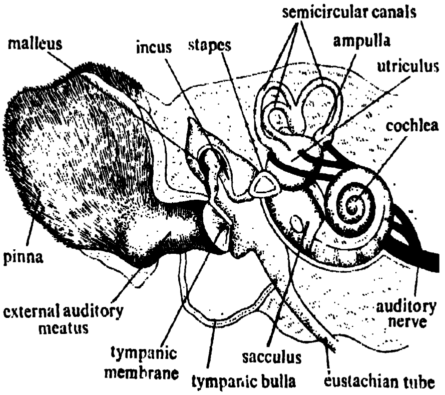
semicircular canals
malleus
incus
stapes
ampulla
utriculus
cochlea
pinna
external auditory meatus
auditory nerve
tympanic membrane
sacculus
tympanic bulla
eustachian tube

Fig. 9.19. Diagrammatic view of the ear of *Cavia*.

External ear. It consists of a movable, flap-like ***pinna*** and a canal called ***external auditory meatus.*** Pinna is responsible for collecting sound wave and sending it inside the ear through external auditory meatus.

Middle ear. The external ear is separated from the middle ear by a tightly stretched membrane called *tympanum*. The middle ear is in communication with buccal cavity by a canal called *eustachian tube*. Within the middle ear, tympanum is connected with the internal ear by three ear ossicles—elongated *malleus*, slightly bent *incus* and triangular, ring-like *stapes*. Malleus is attached with the tympanum and stapes is attached with the opening in the wall of internal ear, called *fenestra ovalis*. The incus is present in between the two. The ear ossicles are responsible for carrying the sound waves to the internal ear and the eustachian tube is for regulating the equilibrium of atmospheric pressure.

Internal ear. It consists of a bony labyrinth which is filled up with a fluid called *perilymph*. Within the perilymph a *membranous labyrinth* is suspended which contains another fluid called *endolymph*. The membranous labyrinth consists of following parts—lower *sacculus*, at the top of which lies the *utriculus* with which three *semicircular canals* are connected. The sacculus is drawn into a spirally coiled *cochlea* which contains special receptor cells called *organ of Corti*. Fig. 9.20 shows the details of cochlea in cross-section. The bony cochlear canal encloses three cavities. The *scala vestibuli* is bounded by the vestibular membrane and located above the cochlear duct. The *scala tympani* is situated below

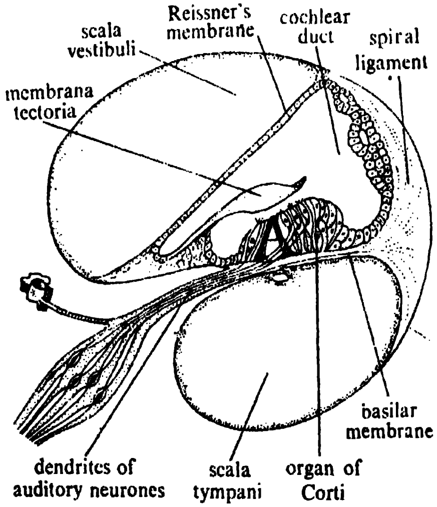
scala vestibuli
Reissner's membrane
cochlear duct
spiral ligament
membrana tectoria
basilar membrane
dendrites of auditory neurones
scala tympani
organ of Corti

Fig. 9.20. Cross-section of cochlea of *Cavia* showing the location of the organ of Corti.

the cochlear duct. The *scala media* is the cavity of the cochlear duct itself. The scala vestibuli and scala tympani are the perilymphatic spaces, while the scala media is filled with endolymph. The Reissner's membrane and basilar membrane are the demarkating partitions between the three cavities as in the figure. The *organ of Corti*, the receptor apparatus for hearing, is supported on the basilar membrane inside the cochlear duct. The organ of Corti is composed of differentiated cells arranged in orderly rows. The semicircular canals, utriculus and sacculus are responsible for balancing.

ENDOCRINE SYSTEM

The chemical co-ordination within the body is done by several ductless glands called endocrine glands. These glands pour their contents directly in the blood. Following endocrine glands are present: **Thyroid gland.** It is placed beneath the thyroid cartilage of the larynx. It is a soft, two-lobed structure. It secretes an iodine containing compound called *thyroxine*. It is responsible for the growth of the animal. **Parathyroid glands.** Two pairs of round glands are present in close association with the thyroid. The secretion is responsible for calcium and phosphorus metabolism and thus helps in bone formation. **Thymus gland.** It is a soft, pink coloured gland present near the base of the aorta. In the young, it is large and the size gradually diminishes with age. It's secretion retards untimely sexual maturity. **Pituitary gland.** Most important of all endocrine glands, it is present on the hypophysis of the diencephalon. Through its secretion it not only controls important vital activities but also controls the functioning of other vital glands. **Adrenal gland.** This gland is present in front of each kidney as a yellow and soft body. It is distinctly separated into two regions—cortex and medulla. Hormones produced by both the parts are important. The secretion of medullary part called *adrenaline* influences the sympathetic activity. **Islets of Langerhans.** These are present as minute patches within the pancreas. It produces *insulin.* Insulin controls the level of sugar in blood. **Gonads.** The activity of ductless glands affects the working of reproductive organs and specially the development of secondary sexual characters.

EXCRETORY SYSTEM

Removal of nitrogenous metabolic wastes and excess of water is done by a pair of kidneys. The kidneys together with several other structures constitute the excretory system.

A pair of *metanephric kidneys* is located on the dorsal posterior side of the abdominal cavity. The kidneys are retroperitoneal in position. The two kidneys are not located on the same line. The right kidney is situated little up from the level of the left kidney. The bean-shaped kidneys are notched on their inner surfaces. The notched region is called *hilus.* Renal artery and renal vein enter into the kidney through hilus. Internally each kidney presents two regions. The cortex is outer and medulla is inner in position. Each kidney is made up of a number of *nephrons*. Each nephron is made up of a *Bowman's capsule* having a tuft of capillaries called *glomerulus* inside and a long convoluted tube differentiated into *proximal tubule*, *loop of Henle* and *distal tubule* (Fig. 9.21). The cortex houses the Bowman's capsules and medulla houses the tubules. All the tubules converge and open into

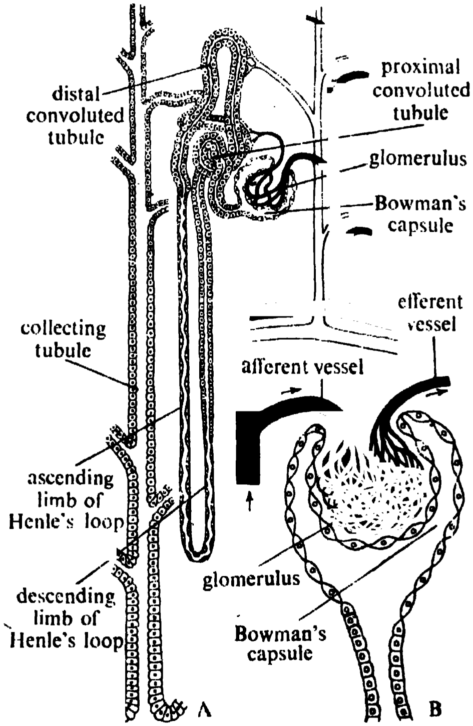

Fig. 9.21. A nephron of *Cavia*. A. A complete unit. B. An enlarged view of a renal corpuscle.

taken into the marsupium of the mother. The marsupium is a fold of skin on the ventral side of the females and it is supported by epipubic bone.

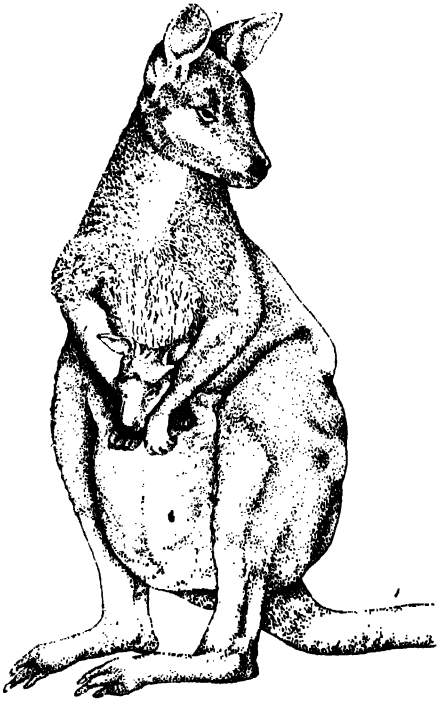

Fig. 9.24. Some interesting mammals (Contd.). *Macropus* (Kangaroo) in sitting posture. Note that the young is placed in the marsupium.

In the marsupium the youngs are fed on milk secreted by true mammary glands. The young comes out of the marsupium when it is 4 months old.

PHASCOLARCTOS. *Phascolarctos* or Koala is an arboreal marsupial which lives on the branches of Eucalyptus. It carries the young on its back (Fig. 9.25). Presence of cheek pouches, enlarged caecum and vestigial tail are some of the peculiar features.

SOREX. *Sorex* or Shrew is a rat-like mammal belonging to the order Insectivora (Fig. 9.26A). The colour of body is reddish brown. The body is about three inches in length. The body includes a tail. The tail is about 2 inches in length. The snout is elongated. Eyes are small. The first pair of incisors are long. Dental formula is $\frac{3.1.3.3.}{2.0.1.3}$ It lives in tunnels and feeds on insects and worms. They are distributed in Asia, Europe and North America. The generic name of Indian shrew is *Soriculus*.

ERINACEOUS. *Erinaceous* or Hedge hog (Fig. 9.26B) is found in Asia, Africa and Europe. The hairs in hedge hog are modified into sharp and pointed spines on the dorsal side. A band of muscles passes along the sides of the body, over the neck and the base of the tail to aid in the movement of the spines. When afraid, the animal rolls to form a ball. They are nocturnal and feed on insects, molluscs, fruits and small birds. They hibernate in winter.

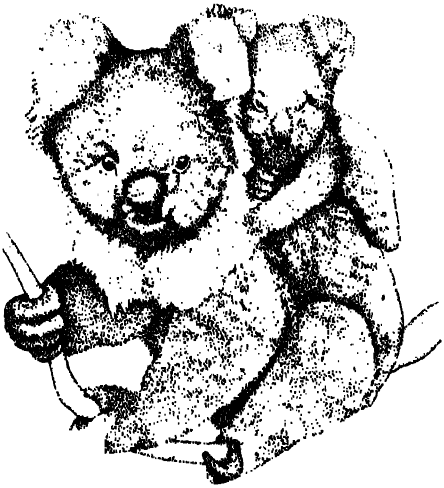

Fig. 9.25. Some interesting mammals (contd.). A. *Phascolarctos* (Koala). Note that mother carries the young on her back.

PTEROPUS. *Pteropus* (or flying fox) is a member of the order Chiroptera (Fig. 9.26C). They are

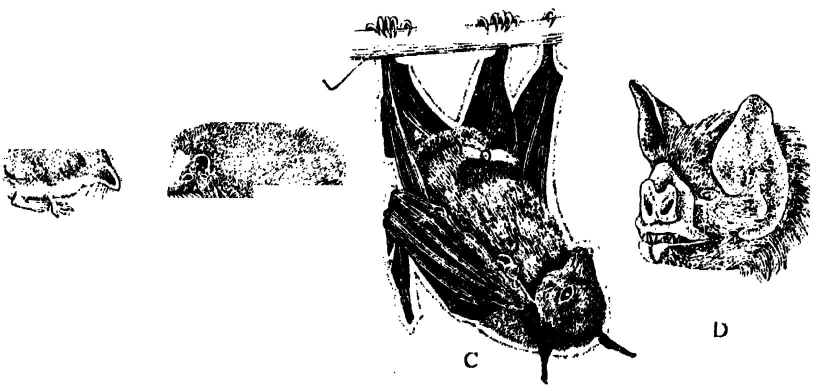

Fig. 9.26. Some interesting mammals (Contd.). A. *Sorex*. *B. Erinaceous*. C. *Pteropus*. D. Head of *Desmodus*.

found in India, Ceylon, Australia and Africa. They are included under the suborder Megachiroptera. The head of Pteropus is fox-like with long snout and large eyes. Tail is absent and the body is covered with brown fur. It is frugivorous in habit.

DESMODUS. *Desmodus* (or vampire bat) is a member of the suborder Microchiroptera and is found in South America. They are small bats. The snout is small. The first digit of the forelimb bears claw. The tail is present. Pinna is large with lobe called *tragus*. Foliaceous nose folds around the nose is present (Fig. 9.26D). The molars bear transverse grooves. It is sanguinivorous and takes the blood of cattle by cutting the skin with its sharp teeth. The pyloric stomach bears a pair of sacs for storage of blood.

DASYPUS. *Dasypus* (or armadillo) is a member of the order Edentata (Fig. 9.27A). They are distributed in Central and South America. Armadillos possess an armour of bony dermal plates or *osteoderms* covered over by epidermal scales. The armour forms two large shields—one on the scapular region and the other on the pelvic region. 3 to 9 bands of transverse armours are present between the scapular and pelvic shields. They are fossorial and nocturnal. The tongue is long and protrusible. They feed on insects.

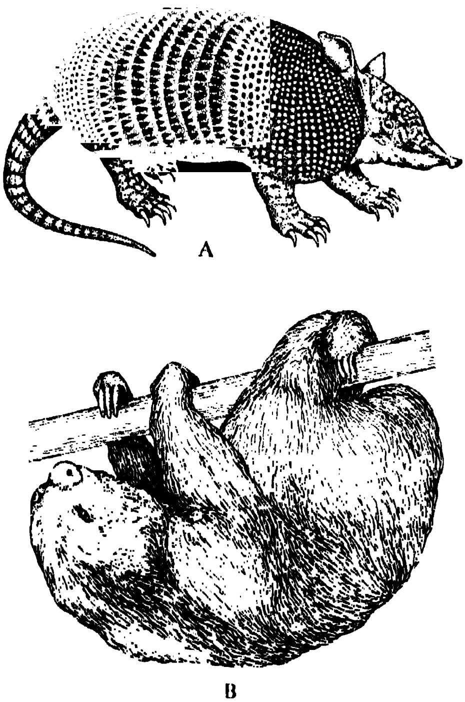

Fig. 9.27. Some interesting mammals (Contd.). A. *Dasypus*. B. *Bradypus*.

BRADYPUS. *Bradypus* (or the three-toed sloth) is a member of the order Edentata (Fig. 9.27B). It is found in the rain forests of Central and South-America. It is an arboreal animal and can walk on land with great difficulty. The forelimbs are longer than the hindlimbs. Each limb bears three digits. The digits are provided with hook like-claws. The animals hang upside down and because of habitually inverted position the hairs are directed in reverse order. They are nocturnal, vegetarian and very sluggish in habit.

MANIS. *Manis* (or scaly ant-eater or pangolin) is a member of the order Pholidota. These burrowing and terrestrial animals are found in India and Africa. The body of Manis is covered with large and round epidermal scales. Some coarse hairs project out between the scales. The limbs are short and strongly built. The digits bear claws. They are plantigrade animals. They can climb trees. Tongue is long. They live on ants and termites.

LEMUR. *Lemur* belongs to suborder Lemuroidea of the order Primate. They are found today in Madagascar. The head is fox-like and the upper lip is with cleft. The eyes are directed sideways and as a result vision is not binocular. The mammae are thoracic and inguinal. Penis has *os penis*. The tail is long but not prehensile. The digits are provided with flat nails excepting the second digit of the foot which is clawed. They are nocturnal, timid and arboreal. The voice is loud.

TARSIUS. *Tarsius* (Fig. 9.28) belongs to suborder Tarsioidea and is found in Indo-Malaya and Phillipines. It is a small (about 6 inches) mammal with long pinnae. Eyes are large, protruding and directed forward. Hindlimbs are longer than the forelimbs. The tarsus of the hindlimb is elongated and hence the name of the animal is Tarsius. The limbs are with five digits and adhesive pads are present in the hand and foot. The digits are provided with nails but the 2nd and 3rd digits of the foot is provided with claws. The tail is long with tuft of hairs at the tip. Head can be turned 180° without turning the body. It is nocturnal, insectivorous and lives in pairs in the hollows of the trees.

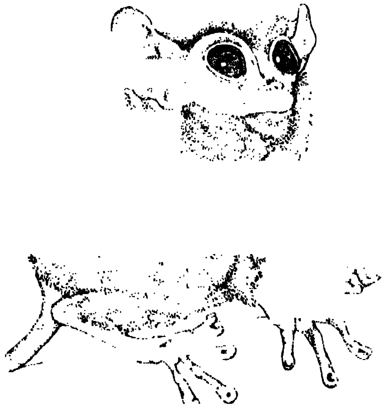

Fig. 9.28. Some interesting mammals (Contd.). *Tarsius*.

ALOUATTA. *Alouatta* (or howling monkey) is a new world monkey belonging to the suborder Anthropoidea. It lives in the forests of South America. This is an ugly-looking monkey. The colour of the hairs is black or brown. The hairs on the forehead are directed backwards while those on the head are directed forwards. Body and limbs are slender and the tail is prehensile. These animals can make a loud howling. The howling apparatus consists of an ossified bag-like outgrowth of the larynx which acts as resonator and a much enlarged bell-shaped hyoid with pharyngeal air sacs. Co-operation amongst the same members is done by specific sound. They can make 12 different types of sound for the purpose.

HYLOBATES. *Hylobates* (or gibbon) is a small sized ape found in Assam and East Asia. The males are black in colour but the females are yellowish. Peculiar feature of these animal is the presence of *ischial callosities*. Forelimbs are large (Fig. 9.29A) and reach the ground even in standing posture. It is frugivorous and arboreal. It swings along the branches of the trees by its arms with great rapidity. It can walk on land using the forelimbs as balancing rods.

PONGO. *Simia* or *Pongo* or urang utan is found in Borneo and Sumatra. Hair colour is reddish brown. The head is short. The eyes lie close together (Fig. 9.29B). Sagittal crest is well developed. The body is strongly built and it is a poor climber. On ground it walks on all four limbs. It makes a platform between two branches of a tree to live there and feeds on plants and fruits.

PAN. *Anthropithecus* or *Pan* or chimpanzee are found in equatorial Africa. The colour of the hair in these apes is black and the animals may attain a height of over 4 feet. The head is provided with prominent brow ridges (Fig. 9.29C). Sagittal crests are well developed. The body is not strongly built and it is a good climber. They build nests on trees and are frugivorous in habit.

GORILLA. Gorillas are found in the forests of tropical Africa. The body is massive and strongly built (Fig. 9.29D) and may attain a length of over 5 feet. The body weight is about 6 maunds. Hair colour is black. The chest is broad and the hands reach the knees in standing posture. Brow ridges are prominent and sagittal crest is well developed. Heavy jaws project forward. Canines are large. On ground the locomotion is bipedal and plantigrade. They live in herds. A family consists of several females and youngs with an old male as the leader. During day time they lead a terrestrial life. They build nests on trees.

PETAURISTA. *Petaurista* (or flying squirrel) belongs to the order Rodentia. They are found in Eastern Himalayas, Africa and America. They are small arboreal mammals with a capacity for gliding from one tree to another. The parachute mechanism is formed by a fold of skin extending from the lateral sides of the body between the two limbs. They are frugivorous.

HYSTRIX. *Hystrix* or porcupine is found in Asia and Africa. American porcupines show variation. Length of the body is about 3 feet. Hairs on the body are modified to form black and white quills on the body and tail. Quills are erected by muscles. Body quills are solid while tail quills are hollow. Coarse long hairs are found on the head. They are herbivorous and live on plant roots.

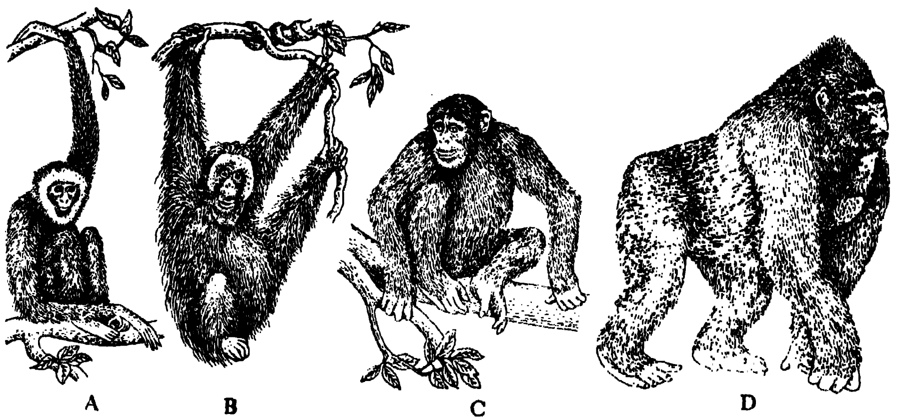

Fig. 9.29. Some interesting mammals (Contd.). A. *Hylobates*. B. *Pongo*. C. *Pan*. D. *Gorilla*.

PHYSETER. *Physeter* or sperm whale comes under the suborder Odontoceti (Fig. 9.30A). These aquatic mammals are of enormous size attaining a length of 60 feet. The head is elongated to form a swollen structure called rostrum. Rostrum is a reservoir of *spermaceti*. The lower jaw bears numerous monophyodont and homodont teeth. Teeth on the upper jaw are vestigial. It feeds mostly on squids and is found on the southern seas. Its intestinal secretion forms a stone-like substance called *Ambergris* which is used in the manufacture of perfumes.

ORCINUS. *Orcinus* or killer whale has a fish-like body (Fig. 9.30B). The length of the body is about 30 feet and the body bears white and black marks. In males the dorsal fin is triangular and pointed while in females the fin is recurved. It is a fierce killer feeding on fishes and other whales.

PLATANISTA. *Platanista* is a dolphin found in the Ganges, Indus and Brahmaputra. The colour of the body is dark gray and the length of the body is 6-9 feet. The head is round. Maxillary crest is well developed. A long beak with sharp teeth on both jaws is present. The eyes are rudimentary.

DOLPHINUS. It is a common marine dolphin. It bears largest number of teeth amongst the whales. Eyes are well developed (Fig. 9.30C).

PHOCAENA. *Phocaena* (or porpoise) is a comparatively small sized whale found in all oceans but is more numerous in the Pacific and the Atlantic. It differs from dolphins in having a beakless and rounded head (Fig. 9.30D). Jaws are with numerous teeth. Dorsal fin is large and bear many tubercles. Paddles are broad with reduced number of phalanges. It is gregarious in habit.

BALAENOPTERA. *Balaenoptera* or blue whale is the largest of all whales (Fig. 9.30E). It may attain a length of more than 100 feet with a weight of 120 tons. The colour of the body is blue above and yellow below. It is also called sulphur-bottom whale. Teeth are absent. The characteristic feature of these whales is that the mouth cavity is provided with whale bone or *Baleen*. Baleen consists of numerous large horny sheets which hang in series from the edge of the upper jaw. The lower ends or the free ends of the plates are fringed which serves to strain from water microscopic organisms which form the food for them. The distribution of blue-whales is restricted to the Antarctic ocean.

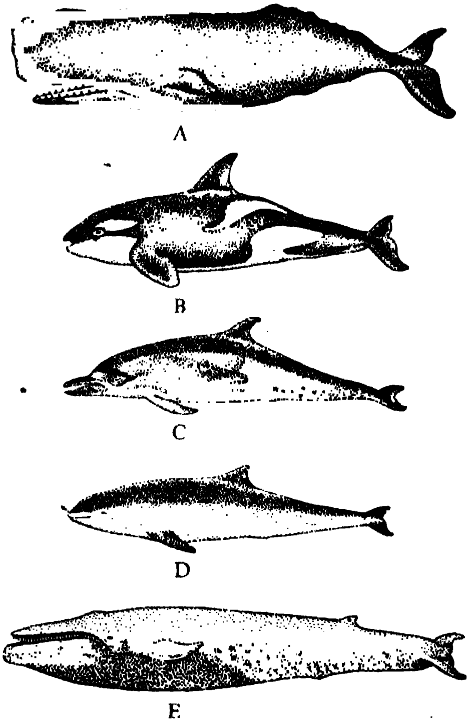

Fig. 9.30. Some interesting mammals (Contd.). A. *Physeter*. B. *Orcinus*. C. *Delphinus*. D. *Phocaena*. E. *Balaenoptera*.

PHOCA. *Phoca* or Seal is a member of the suborder Pinnepedia. They are found in all seas excepting Indian ocean. Body is covered with soft fur. Even the soles and palms are provided with hairs. Proximal part of the forelimb is short but the distal part is elongated forming the paddle. Hindlimbs are directed backwards and its distal part is free. Locomotion on land is effected by wriggling of forelimbs and abdomen. They breed once in a year and during breeding period they come on land.

ODOBENUS. *Odobenus* or walrus is an aquatic carnivore. It is found in the Arctic regions. The body of walrus is strongly built. The upper lip is thick, fleshy and is provided with sensory bristles. In both sexes tusks are present. Tusks are modified upper incisors directed downwards. Modified forelimbs are used in swimming. Hindlimbs are turned forward during locomotion on land. They breed once in two years and during breeding season come on land.

MELURSUS. *Melursus* or sloth bear is a member of the family Ursidae under suborder Fissipedia. They are found in India. The body is covered with long and coarse hairs. The snout is elongated. The lower lip is elongated. The tongue is extensible. Some of the teeth are rudimentary. They live on fruits and honey.

SELENARCTOS. *Selenarctos* or black Himalayan bear is characterised by the presence of a white V-shaped mark on the chest. It is a carnivorous form.

HERPESTES. *Herpestes* (or mongoose) is a member of the superfamily Feloidea (Fig. 9.31A). It is a small and active carnivore. The pinna is short. Legs are short and the digits bear sharp claws. Claws are non-retractile. Mongoose can kill snakes easily. They are found in Asia and Africa.

HYAENA. *Hyaena* is found in Asia and Africa. The Indian hyaena bears stripes on the body. Body is slanted towards the posterior region. Limbs bear 4 clawed digits. The cheek teeth are massive. There is only one molar in each jaw though the molar on the upper jaw is ill developed. They are scavangers though at times they kill smaller mammals and birds.

PANTHERA. *Panthera leo* is the scientific name of lion which is restricted in distribution in South and Central Africa, Mesopotamia and in the Gir forests in India. They are terrestrial and nocturnal animals. The digits bear large and sharp retractile claws. They live in families. A family usually consists of a male, several females and young ones. Males posses mane. Hunting is done mostly by the female members

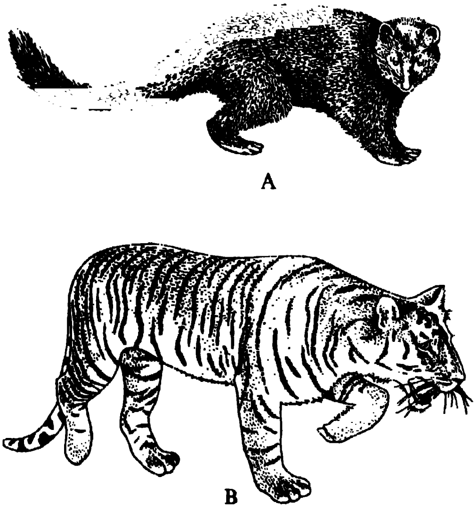

Fig. 9.31. Some interesting mammals (Contd.). A. *Herpestes*. B. *Felis*.

FELIS. *Felis tigris* or Tiger (Fig. 9.31B) enjoys wide distribution throughout Asia to Siberia. It is characterised by having short high skull with large eyes. The claws are highly retractile. The tiger has been given the status of the national animal of India.

HYRAX. *Hyrax* or Pro-cavia or coney is a rabit-like member of the order Hyracoidea. They live in colonies in Ethiopia and Arabia. They possess small pinnae and spilled snout. Testis is abdominal. A single pair of pectoral mammae is present. Incisors are with persistent pulp.

ELEPHANT. Elephants belong to the order Proboscidea. They are largest of living terrestrial animals. Body is massive. The limbs are pillar-like and pentadactylous. Hairs on the body are scanty. A characteristic feature of the elephant is its trunk or proboscis. This prehensile organ is formed by an elongation and fusion of nose and upper lip. The tusks of the elephants are formed by the upper pair of incisors. Elephants are slow breeders. Their longivity is great. Indian elephant, ***Elephas indicus*** differs from its African counterpart ***Loxodonta*** in some features. The Indian elephant is small in size. The pinna is small compared to that of African elephant. In Loxodonta the tusks are large and curved upwards in both sexes. In Elephas the tusks are large in males but in females they just project beyond the lips.

HELICORE. *Helicore* or *Dugong* is a member of the order Sirenia. This aquatic mammal is found in the Red Sea and along the shores of Indian and Pacific ocean. The body is heavy. The tail is fish-like and is with tail fluke. Nostrils are shifted upwards. Number of teeth are reduced. Males have small tusks projecting downwards. The tusks are modified upper incisors.

HORSE. *Equus caballus* or horse is a member of the order Perissodactyla. It has been domesticated by man for centuries. The body is streamlined and suited for swift running. The limbs are long. The middle or third digit is functional. The digits are provided with hoofs. Mane is well developed. *Equus hominis* or Indian ass is a breed produced by crossing a male ass with a female horse. The head of ass is proportionately large. The mane is insignificant.

ZEBRA. *Equus zebra* is a horse-like animal found on the grass covered plains of Africa. The skin is shiny with conspicuous black and yellow colours.

TAPIR. *Tapirus* belongs to family Tapiridae under order Perissodactyla. They are discontinuously distributed and are found in Central and South America, Malay and Indonesia. The digits are stout. There are four digits in the forelimb and three in the hindlimb. The axis of the body passes through the middle digit which is somewhat enlarged. Digits bear hoofs. A short and flexible proboscis formed by the nose and upper lip is present. Number of teeth are 42. It is considered as a primitive form.

RHINOCEROS. ***Rhinoceros*** is a member of the family Rhinocerotidae under order Perissodactyla. The body is massive. The skin is folded and is very thick. Three hoofed digits are present. The axis of the body passes along the middle digit. Characteristic feature of the rhinoceros is the presence of horn (Fig. 9.32A) formed of keratinised hairs. The Indian rhinoceros or ***Rhinoceros unicornis*** found in North Bengal, Assam and Nepal has a single horn. The African rhinoceros, ***Diceros bicornis*** possesses two horns.

PIG. *Sus* is a member of the suborder Suiformes under order Artiodactyla. Body of the pig is stumpy. Colour is dark-gray with fewer number of hairs. Hairs are hard and bristle-like. A row of hard bristle is present on the neck and along the mid-dorsal line. Snout is elongated and nostrils are terminal. Limbs bear four digits, of which the 3rd and 4th reach the ground. Digits are provided with hoofs. Original dental formula is retained. Dental formula is $\frac{3.1.4.3}{3.1.4.3}$. Canines of both jaws form tusks specially in males. They are gregarious animals and prefer marshy places.

HIPPOPOTAMUS. *Hippopotamus* is an amphibious mammal belonging to the suborder Suiformes under order Artiodactyla. They are found in Africa. Body is massive and measures 14 feet in length. Muzzle is broad. Nostrils, eyes and pinnae are shifted more towards the dorsal side of the head. The tail is short. The skin is thick with few hairs. Each limb bears 4 hoofed digits. They are herbivorous. Red sweat is a peculiarity in these animals.

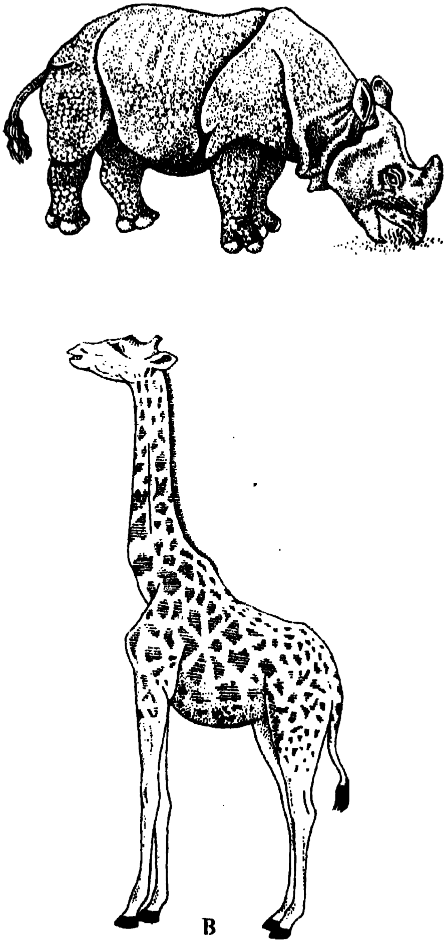

Fig. 9.32. Some interesting mammals (Contd.). A. *Rhinoceros*. B. *Giraffe*.

CAMEL. Camel is a member of the suborder Tylopoda under order Artiodactyla. These animals exhibit a good number of modification of structures for adaptation to a life in deserts. The Arabian camels have a single hump and African camels have two humps. *Llama* is a cousin of the camels. Its body is covered with wooly hairs. The neck is long and upright. Hump is absent. Llama is found in South America.

CHEETAL. *Axis axis* or spotted deer or Cheetal is a member of the family Cervidae under the order Artiodactyla. They are found in plenty in the jungles of Ceylon and India. The body colour is brown with white spots. A black line passes along the spine. The throat and belly is white. They live in herds. Male possesses antlers.

MUSK DEER. *Moschus* or musk deer is found in Central Asia and the Himalayas. The colour is grayish brown with gray spots on the back. Hindlimbs are longer than the forelimbs. Horns in both sexes are absent. Tail is small. The males are characterised by having a musk pouch on the abdomen. Musk is paste like in consistency and has a strong and sweet smell. It is used in the manufacture of perfumes.

GIRAFFE. *Giraffe camelopardalis* or Giraffe is found in Tropical Africa. The body is large. The forelimbs are longer than the hindlimbs. The neck is very much elongated though the number of cervical vertebrae remains constant (Fig. 9.32B). The colour of the body is bright yellow with brownish spots at intervals. The tongue is prehensile. Both sexes bear small horns which remain permanently covered by velvet.

NIL GAI. *Bos laphus* or blue bull or nil gai is a member of the family Bovidae under the order Artiodactyla. They are found in India excepting Bengal and Assam. The colour of the body is 'steel-gray'. A white ring below each fetlock and two white spots on the cheek are characteristic of these animals. Males possess hollow horns.

CLASSIFICATION

CLASSIFICATION IN OUTLINE

CLASS **Mammalia**

Subclass **Prototheria**
Order *Monotremata*, e.g., *Ornithorhynchus* and *Tachyglossus*.

Subclass **Allotheria**
Order *Multituberculata*, e.g., *Plagiaulax*.

Subclass **Uncertain (?)**
Order *Triconodonta*, e.g., *Priacodon*.

Subclass **Theria**
Infraclass (A) *Pantotheria*

Order 1 *Pantotheria*, e.g., *Amphitherium*.

Order 2 *Symmetrodonta*, e.g., *Spalacotherium*.

Infraclass (B) *Metatheria*
Order *Marsupialia* e.g., *Macropus*.

Infraclass (C) *Eutheria*
Cohort (A) UNGUICULATA
Order 1. *Insectivora*, e.g., *Sorex*.
Order 2. *Dermoptera*, e.g., *Cynocephalus*.
Order 3. *Chiroptera*.
Suborder (*i*) Megachiroptera, e.g., *Pteropus*.
Suborder (*ii*) Microchiroptera, e.g., *Desmodus*.
Order 4. *Primates*
Suborder (*i*) Lemuroidea, e.g., *Lemur*.
Suborder (*ii*) Tarsioidea, e.g., *Tarsius*.
Suborder (*iii*) Anthropoidea, e.g., *Ateles*, *Homo*.
Order 5. *Tillodontia*, e.g., *Tillotherium*.
Order 6. *Taeniodontia*, e.g., *Stylinodont*.
Order 7. *Edentata*.
Suborder (*i*) Palaeanodonta, e.g., *Metacheiromys*.
Suborder (*ii*) Xenarthra, e.g., *Tolypeutes*.
Order 8. *Pholidota*, e.g., *Manis*.

Cohort (B) GLIRES
Order 1. *Rodentia*.
Suborder (*i*) Sciuromorpha, e.g., *Petaurista*.
Suborder (*ii*) Theridomyomorpha, e.g , *Anomalurus*.
Suborder (*iii*) Castorimorpha, e.g., *Castor*.
Suborder (*iv*) Myomorpha, e.g., *Mus*.
Suborder (*v*) Caviomorpha, e.g., *Agouti*.
Suborder (*vi*) Hystricomorpha, e.g., *Cavia*.
Suborder (*vii*) Bathyergomorpha, e.g., *Heterocephalus*.
Order 2. *Lagomorpha*, e.g., *Oryctolagus*.

Cohort (C) Mutica
Order 1. *Cetacea*.
Suborder (*i*) Archaeoceti, e.g., *Protocetus*.
Suborder (*ii*) Odontoceti e.g., *Phocaena*.
Suborder (*iii*) Mysticeti, e.g., *Balaena*.

Cohort (D) FERUNGULATA
Order 1. *Carnivora*.
Suborder (*i*) Creodonta, e.g., *Tricentes*.
Suborder (*ii*) Fissipedia, e.g., *Lutra*.
Suborder (*iii*) Pinnipedia, e.g., *Phoca*.
Order 2. *Condylarthra*, e.g., *Phenacodus*.
Order 3. *Litopterna*, e.g., *Thoatherium*.
Order 4. *Notoungulata*, e.g., *Arcostylops*.
Order 5. *Astrapotheria*, e.g., *Astrapotherium*.
Order 6. *Tubulidentata*, e.g., *Orycteropus*.
Order 7. *Pantodonta*, e.g., *Pantolambda*.
Order 8. *Dinocerata*, e.g., *Prodinoceras*.

Order 9. *Xenungulata*, e.g., *Carodnia*.
Order 10. *Pyrotheria*, e.g., *Pyrotherium*.
Order 11. *Proboscidia*, e.g., *Elephas*.
Order 12. *Embrithopoda*, e.g., *Arsinotherium*.
Order 13. *Hyracoidea*, e.g., *Hyrax*.
Order 14. *Desmostyliformes*, e.g., *Desmostylus*.
Order 15. *Sirenia*, e.g., *Dugong*.
Order 16. *Perissodactyla*
  Suborder (*i*) Hippomorpha, e.g., *Equus*.
  Suborder (*ii*) Ceratomorpha, e.g., *Tapirus*.
Order 17. *Artiodactyla*
  Suborder (*i*) Suina, e.g., *Sus*.
  Suborder (*ii*) Tylopoda, e.g., *Camelus*.
  Suborder (*iii*) Ruminantia, e.g., *Bos*.

CLASSIFICATION WITH CHARACTERS

Classification of Mammalia poses a difficult problem. Different authors have classified Mammalia in different schemes. The scheme followed here is mainly based on Edwin H. Colbert (1955).

SUBCLASS PROTOTHERIA

Females of this subclass lay eggs and have mammary glands devoid of teats. A distinct cloaca is present. Nasal and premaxilla are drawn out to form a rostrum. Digits are webbed.

Order **Monotremata.** The Monotremes occupy a most interesting position among mammals because of their distribution, anatomical peculiarities and systematic position. The reptilian and mammalian characters present in the Monotremes lead one to think that mammals have evolved from reptiles putting a step on the Monotremes.

Distribution. The distribution of Monotremes is restricted. They are found in Australia, Tasmania and New Guinea.

External morphology

(1) Body is covered over with soft hairs. Hairs on the dorsal side may be coarse or spine-like. (2) Digits end in sharp claws and are webbed. (3) Mammary glands are devoid of teats. The tubular glands open in shallow depression on the ventral side. (4) Pinna is distinct but small. (5) Tail may be present or absent. (6) In males, poison spur is present. (7) Nictitating membrane is present.

Skeletal system

SKULL. (1) Sutures of skull are obliterated. (2) Auditory ring is incomplete and is loosely attached with the skull. (3) Lacrymal and alisphenoid are absent. (4) Nasal and premaxilla are drawn out into a rostrum. (5) Pterygoid bone is present. (6) Jugal is reduced.

JAW BONES. (1) Angular and coracoid processes are ill developed. (2) Mandibular symphysis is absent. (3) Teeth are replaced by a horny pad in adults. Youngs possess teeth. Dental formula in young stage is $\frac{0.1.2,3}{5.1.2.3}$.

VERTEBRAL COLUMN. (1) Epiphysis is ill developed. (2) Zygapophyses in cervical vertebrae are ill developed. (3) Tharacolumbar vertebrae are 19, sacral 2–4 in number. Caudal vertebrae are variable in number. (4) Cervical ribs are present.

PECTORAL GIRDLE. (1) It is built in typical reptilian plan. (2) Scapula is elongated and is without spine. (3) Acromian process is well developed. (4) Coracoid is large.

PELVIC GIRDLE. (1) Acetabulum is perforated. (2) Ischio-pubic symphysis is present. (3) Epipubic bone is present.

STERNUM. 'T'-shaped interclavicle is present in the sternum.

LIMBS. (1) Humerus is flat having a little developed olecranon process. (2) Centrale is not separated. (3) Femur is flat with prominent trochanter. (4) Patella is large.

Internal organs

(1) Tongue is long and sticky.

(2) Saliva is of thick consistency.

(3) Sweat and sebaceous glands are present.

(4) Cloaca is well developed.

(5) Erectile penis is present in males and testes are abdominal in position.

(6) Paired oviducts open directly into cloaca.

(7) Ventral abdominal vein is present.

(8) The cerebrum of brain is smooth and does not cover the cerebellum. Corpus callosum is absent.

(9) Eggs are provided with much yolk and the egg shell is leathery.

(10) Segmentation is meroblastic.

(11) Body temperature ranges between 25°C and 28°C.

Only three genera are living today. They are platypus or duck-bill, *Ornintho-rhynchus*, and the spiny ant-eaters, *Echidna* or *Tachyglossus* and *Zaglossus* or *Proechidna*. The structural differences between Ornin-thorhyncus and Tachyglossus are shown in Table Chordata—15.

TABLE CHORDATA—15

Points	Ornithorhyncus	Tachyglossus
Habit and habitat	(*a*) Lives in burrows on river banks.	(*a*) Terrestrial and lives on land with soft soil.
	(*b*) Good swimmers. Swimming is done by paddling of limbs and body undulations.	(*b*) Adapted to terrestrial life.
	(*c*) Lives on molluscs and worms.	(*c*) Lives on ants.
	(*d*) Can not roll up into a ball for pro-	(*d*) Can roll up into a ball for protec-
	(*e*) Pinna is small and remains under cover of hairs.	(*e*) Pinna is large, tubular and lies just behind the eye.
External morphology	(*a*) Body [illegible] d over with brown under fur and harsher outer fur.	(*a*) Body is [illegible] d over with strong pointed spines and coarse hairs. Spines are absent on the ventral surface.
	(*b*) A flat bill, like that of a duck is present. The bill is hairless with tactile organs in pits.	(*b*) A long pointed and tactile rostrum is present.
	(*c*) Nictitating membrane is present.	(*c*) Nictitating membrane is absent.
	(*d*) Tail is broad and flat.	(*d*) Tail is vestigial.
	(*e*) Digits are webbed.	(*e*) Digits are not webbed.
Internal structures	(*a*) Teeth- present in early stage but teeth are replaced by horny pad in adults.	(*a*) Teeth-absent at all stages of life.
	(*b*) Tongue is small.	(*a*) Tongue is long and protrusible. Secretion of salivary glands is sticky.
	(*c*) Eardrum is very small.	(*c*) Eardrum is large.
	(*d*) Brain is relatively small.	(*d*) Brain is relatively large.
	(*e*) Skeletal framework is rather simple.	(*e*) Skeletal framework is complex.
	(*f*) Gynaecomastism is supposed to be present.	(*f*) Gynaecomastism is definite.

Affinities of Monotremata

REPTILIAN AFFINITIES. (1) Presence of ectopterygoid in skull. (2) Presence of provomer. (3) Zygomatic arch is perforated by a temporal canal, which is believed to be post-temporal fossa of Reptiles. (4) At the posterior end of palate, a pair of bones of doubtful nature is present. According to many they represent some reptilian skull bone. (5) Ribs are single headed (excepting cervical ribs). (6) Cervical ribs are present. (7) Coracoid is plate-like and epicoracoid is present. (8) 'T'-shaped interclavicle. (9) Epipubic bone is present. (10) Acetabulum is perforated. (11) Absence of epiphysis. (12) Corpus callosum is absent and anterior commissure is well developed. (13) Ventral abdominal vein is present. (14) Body temperature is not constant. (15) Cloaca is present and it is shallow. (16) Testis is abdominal. (17) Presence of different glands in the oviduct. (18) Oviparous and meroblastic segmentation.

Presence of strong reptilian features in Monotremata speaks of its primitiveness. These primitive mammals have failed to cope up with many of the evolutionary transformations which culminated in the establishment of better characteristics in higher mammals.

Avian affinities. (1) Shape of the beak in platypus resembles birds. (2) Teeth are absent. (3) Presence of webbed feet. (4) Sutures of the skull are obliterated. (5) Presence of spur in the tarsal region. (6) Presence of oil gland.

The relationship between monotremes and birds does not stand on a solid ground. The converging characters seen in them are due more to the fact that both possess common reptilian ancestry.

AFFINITIES WITH MARSUPIALS. (1) Structure of skull. (2) Presence of Marsupial bone. (3) Mandibular inflection. (4) General contour of brain. (5) Bulbourethral gland. (6) Resemblance between foetal monotreme and marsupial. (7) Mode of milk secretion.

Considering the similarities, Gregory (1947) has proposed that monotremes originated from some pre-marsupial stalk and their present features are due to specialization. He has included both monotremes and marsupials in a subclass 'Marsupiontia.' But most accepted view is that monotremes originated from the principal line of evolution of mammals.

MAMMALIAN AFFINITIES. (1) Presence of hair, mammary glands, oil gland and sweat glands. (2) Double occipital condyle. (3) Single jaw bone, dentary. (4) Presence of palate. (5) Jaw attachment is craniostylic. (6) Sternum is segmented. (7) Cervical vertebrae are seven. (8) Pinna is distinct. (9) Circulatory system is typically mammalian. (10) Diaphragm is present. (11) Presence of proportionately large ear ossicles. (12) Cochlea is slightly coiled. (13) Cerebellum is well developed. (14) Presence of corpora quadrigemina. (15) Fertilization is internal.

Though monotremes show affinity with non-mammalian groups, the above mentioned characters unequivocally speak of close and firm affinity with mammals.

Phylogenetic consideration of Monotremes

Two logical and reasonable views have been put forward to explain the phylogeny of Monotremes. In one view it has been expressed that the Monotremes evolved independently from the early mammal-like reptiles and continued to survive in isolation as basically primitive mammals marked with certain specializations.

The other view advocates that Monotremes have derived from very early Marsupials and owe their peculiar characters to divergent specialisation. These specialisations are retention, degeneration and reversion of characters.

Among the mammals the Monotremes are very much controversial. They possess primitive, degenerated and specialised features. It is reasonable to conclude that Monotremes originated as a side line from the main line of mammalian evolution and have retained the characters through which ancestors of higher mammals have passed.

SUBCLASS ALLOTHERIA

Fossils forms of Allotheria have been found from the sediments of Jurassic age. The group was highly specialised. Teeth pattern showed that they were herbivorous.

Order *Multituberculata.* Skull was heavy with massive lower jaw. Zygomatic arch was strongly built. Incisors were elongated. Diastema was present. Upper and lower molars were with longitudinal rows of cusps. In primitive forms, two parallel rows of cusps were present in both upper and lower molars, but in later forms three rows of cusps appeared on the upper molars. Example: *Plagiaulax.*

SUBCLASS UNCERTAIN (?)

Fossil forms of a group of mammal like *Triconodont* have been discovered. They survived during the middle and late Jurassic age. Skull in parts, teeth, jaws and palates have been discovered. The naming of the subclass has not yet been complete.

Order *Triconodonta.* Size was not bigger than present day cats. Jaws were elongated with considerable array of differentiated teeth. There were four incisors, a single canine and nine post-canines. According to some the post-canines too were differentiated into four premolars and five molars making the dental formula as 4.1.4.5. The molar teeth of the triconodonts had three cusps arranged in rows from which the order derived its name. Example: *Priacodon.*

SUBCLASS THERIA

Mammals included in this subclass do not lay eggs but give birth to young ones. Mammary glands are provided with nipples or teats. The ureters open directly into a urinary bladder. The subclass is divided into three infraclasses of which one is extinct.

Infraclass (A) *Pantotheria.* They were also known as trituberculates. Jaws were long and slender with differentiated cheek teeth. They persisted during the middle and upper Jurassic. They were divided into two orders.

Order (1) *Pantotheria.* They had four incisors, one canine, four premolars and seven molars on each half of their elongated upper and lower jaws. The upper molars were triangular in shape having a prominent cusp called *protocone* on the inner apex. The outer side of the molar was provided with many cusps and cuspules. Example: *Amphitherium.*

Order 2. *Symmetrodonta.* They are considered by many as "experiment in evolution". They resemble the Pantotheria in many respects. Each molar tooth when looked at in crown view presents three cusps arranged in a perfect symmetrical triangle. Because of this symmetry of cusps in molar they are known as symmetrodonts. Example: *Spalacotherium.*

Infraclass (B) METATHERIA. The youngs are born in an immature condition and undergo further development in marsupium of the female. Mammary glands with teats open into the marsupium. Allantoic placenta is absent.

Order **Marsupialia.** The marsupials form a distinct group for their anatomical peculiarities, distribution, adaptation and evolutionary history.

Distribution. Marsupials were universal in distribution during Cretaceous period and were in keen competition with the placentals. But during Cenozoic era, the placentals increased in number at such a rapid rate that the marsupials failed in competition and consequently became exterminated from many parts of the globe. In Cenozoic era, Australia and South America became separated from the main land mass. The separated lands contained marsupials as well as some placentals. Marsupials, defeated in competition with placental mammals in other parts of the world, flourished in these separated land masses of Australia and South America. Later on South America was invaded by placentals again and their influx led to the extinction of many marsupials there. Thus marsupials, like true placentals, explored all the possible niches but failed to survive in all the regions. Today they are having a restricted distribution in Australia and South America.

External morphology

(1) Body is covered over with soft fur. (2) Pinna is well developed. (3) Most of the female members possess *marsupium*. (4) Mammary glands have teats. (5) Tail is well developed and helps in balancing. (6) A strange specialisation is seen in the hind foot. The second and third toes are slender and remain enclosed in a sheath of skin. These two together are known as syndactylous digits which form a sort of two-pronged comb. The fourth toe is largest. All digits end in claws. (7) Forelimbs are shorter than the hindlimbs.

Skeletal system

SKULL. (1) Skull is small with well developed sagittal crest. (2) Sutures of the skull are present (Fig. 9.33A). (3) Jugal takes part in the formation of glenoid fossa. (4) Tympanic bulla is partly formed by alisphenoid and is incompletely united with the skull. (5) Orbital and temporal fossae are confluent. (6) Zygomatic arch is complete. (7) Pterygoid is small. (8) Inward inflection of lower jaw is present (Fig. 9.33B). (9) Mandibular symphysis is weak. (10) Palate is fenestrated. (11) Dentition is heterodont, thecodont and monophyodont (excepting last premolars). Number of incisors vary. There are five upper incisors and four lower incisors. Dental formula is $\frac{5.1}{4.1}\,\frac{3.4}{3.4}$.

VERTEBRAL COLUMN

Vertebral column is divided into five regions. Cervical vertebrae are seven in number. Thoracic vertebrae are about thirteen in number and are provided with ribs. Lumbar vertebrae are seven in number and are devoid of ribs.

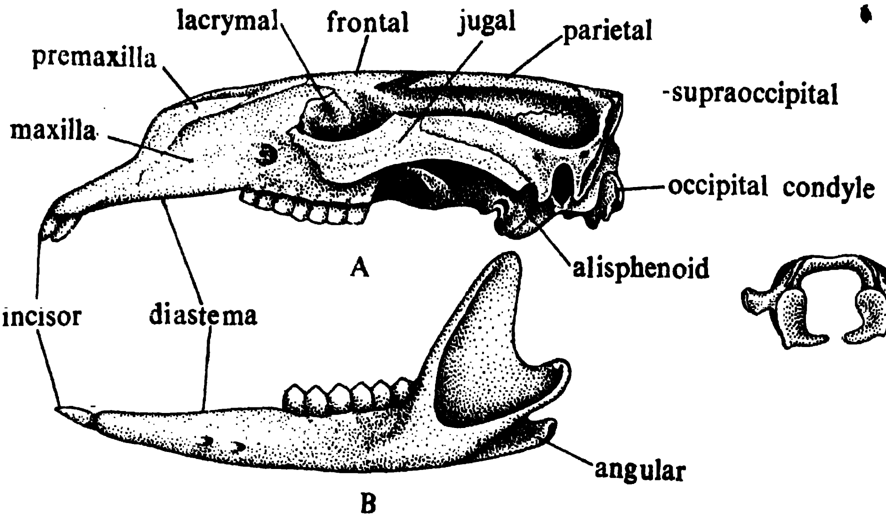

Fig. 9.33. Skull (A), lower jaw (B) and Atlas (C) of *Macropus*.

Cervical vertebrae are perforated and vertebral artery passes through the perforation. Caudal vertebrae are with 'chevron bone' excepting in Koala and Wombat. Atlas is incomplete (Fig. 9.33C) and is provided with cartilage in the ventral incomplete side.

GIRDLES AND LIMBS

Coracoid is well developed in embryonic stage but becomes reduced into a rod-like structure in the adult. Coracoscapular line of fusion persists for a long time. Acromion, metacromion and scapular spine are present. Clavicle is well developed. An epipubic bone for the support of the marsupium is present but it is not homologous to reptilian epipubic bone. Humerus is with epicondylar foramen. A parafibula bone in the form of a narrow rod may be present on the outer side of the fibula. The 4th toe in the hindlimb is the largest and serves as the axis of the foot.

DIGESTIVE SYSTEM

Teeth are heterodont, thecodont and monophyodont. The last premolar is an exception. Number of premolars may be $\frac{3}{3}$ or $\frac{4}{4}$. Molars bear three cusps; often an additional small cusp may be present. Shape and size of the stomach is variable. A large caecum is present in herbivorous forms. Caecum is absent in carnivorous forms.

CIRCULATORY SYSTEM

The fossa ovalis in the interauricular septum is absent. Each superior vena cava receives an azygos vein. Auriculoventricular valves are membranous.

URINOGENITAL SYSTEM

Anal and urinogenital apertures are enclosed by a common sphincter muscle. Ureters run between the genital ducts in both sexes. Oviducts remain separate and uterus and vagina are paired (Fig. 9.34). Testes are abdominal and lie infront of the penis. The glans penis is bifurcated. Youngs are born alive in an immature state seven days after fertilization. Youngs are taken by the mother in her marsupium where the embryos remain attached to the nipples of the mother. Yolk-sac placenta is common in all. But in *Parameles*, an allantoic placenta is present. It is structurally very simple and remains functional for a short period.

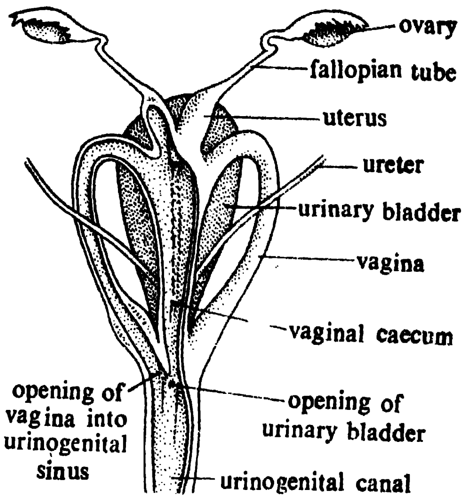

Fig. 9.34. Female reproductive system of *Macropus*. Right uterus, vagina and vaginal caecum are exposed.

NERVOUS SYSTEM

The brain is small with little convolutions. Olfactory lobes are comparatively large. Corpus callosum is either absent or poorly developed. Anterior commissure is very prominent.

Classification of Marsupialia

Formerly two different schemes, one on the basis of the character of teeth and the other on the basis of the features of toes in the hindlimb, were made to classify the order Marsupialia. As scheme based on single character is insufficient to meet the demand of a perfect classification, Simpson has proposed a third scheme. His scheme has taken into consideration the six marsupial groups as independent units and he has placed them under six superfamilies. The three schemes are given below:

First scheme (on the basis of teeth):

Order *Marsupialia*
- Division I. Polyprotodontia
  - Family (*i*) Didelphoidea
  - (*ii*) Dasyuroidea
  - (*iii*) Borhyaenoidea
  - (*iv*) Perameloidea.
- Division II. Diprotodontia
  - Family (*i*) Caenolestoidea
  - (*ii*) Phalangeroidea.

Second scheme (on features of hind toes):

Order *Marsupialia*
- Division I. Didactyla
  - Family (*i*) Didelphoidea
  - (*ii*) Dasyuroidea
  - (*iii*) Borhyaenoidea
  - (*iv*) Caenolestoidea.

Division II. Syndactyla
Family (i) Perameloidea
(ii) Phalangeroidea.

Simpson's scheme:
Order *Marsupialia*
Superfamily I. Didelphoidea
Family (i) Didelphidae Ex. Opposum.
Superfamily II. Dasyuroidea
Family (i) Dasyuroidea. Ex. Gerboa, Tasmanian wolf.
Family (ii) Notoryctidae. Ex. Marsupial mole.
Superfamily III. Borhyaenoidea
Family (i) Borhyaenidae. Ex. Borhyaena
Superfamily IV. Perameloidea
Family (i) Peramelidae. Ex. Perameles.
Superfamily V. Caenolestoidea
Family (i) Caenolestidae. Ex. Dipilus.
Superfamily VI. Phalangeroidea
Family (i) Phalangeridae. Ex. Koala.
Family (ii) Phascolomidae. Ex. Wombat.
Family (iii) Macropodidae. Ex. *Macropus* (Kangaroo)
Family (iv) Diprotodontidae. Ex. Nototherium.

Adaptive radiation is Marsupials

Marsupials have explored all possible ecological niches and have tried to master all available habitats. Because of their adaptation to diverse habitats, the different members have undergone through various anatomical modification. A good degree of adaptive radiation is exibited by different members of the groups. They are discussed below:

Superfamily Didelphoidea. Members belonging to this superfamily are found in North and Central America and in Australia. Most of the members are *Arboreal*, only one species is *aquatic* They are small in size and insectivorous. They are characterised by the presence of an elongated muzzle, well-developed nail, less opposable hallux and a long prehensile tail. The aquatic forms have webbed feet. Marsupium is absent or incompletely formed. The American forms pretend to be dead when captured.

Examples: *Didelphys* (opposum), *Chironectes*.

Superfamily Borhyaenoidea. Most of the members are extinct. They were distributed in South America. The members were bear-like in size, short legged, large headed and carnivorous in habit.

Examples: Borhyaena, Protohylacinus.

Superfamily Dasyuroidea. Members belonging to this superfamily are restricted in Australia. A diverse adaptation is encountered among the different members. They are:

(1) *Carnivorous*. Examplified by Tasmanian devil and Thylacine. These animals have rudimentary pollex and small, clawless hallux. Most members are terrestrial with well developed four-toed foot and marsupium. The tail is long and nonprehensile.

(2) *Semiarboreal*. Members are represented by *Phascogale*. These are slender bodied rat-like creatures with bushy tail.

(3) *Ant-eater*. Members are represented by *Myrmecobius*. These are pouchless small rat-like animals characterised by the presence of black bands across the lumbar and sacral regions.

(4) *Fossorial*. Members are represented by *Notoryctes*. They are small in size with well equipped body adaptation for burrowing. They live in sandy deserts. The limbs are short but powerful having five digits. Claws in the 3rd and 4th digits of the forelimbs are large, flat and triangular. Dorsal side of the head is provided with protective shield. The tail is short and is covered by hairless horny skin. Pinna is absent and eyes are vestigial. Pouch is well developed and the opening is directed backward.

Superfamily Perameloidea. Members belonging to this superfamily are restricted in Australia in its grassy lands. The animals are smaller than rabbit in size. The animals have elongated and pointed muzzle. Pinna is present in some and the tail is small. The 3rd and 5th digits are either vestigial or absent. In the hindlimb the 4th toe is the largest, 2nd and 3rd ones are small and webbed and the 1st toe is vestigial. The opening of the marsupium is directed backward.

Example: *Perameles* (Bandicoot), *Macrotis* and *Thylacomys*. The last one is carnivorous and others are omnivorous.

Superfamily Caenolestoidea. The members are found in South America. They are small, rodent-like and terrestrial in habit. Enlargement of median pair of lower incisors is a characteristic feature.

Examples: *Caenolestes, Orolestes, Rhynocolestes.*

Superfamily Phalangeroidea. A high degree of adaptive radiation is exhibited by the members of this superfamily. The type of adaptation and characteristics for each type of adaptation is given below:

(1) *Arboreal*. Both the limbs and the tail is prehensile in the arboreal forms. The 2nd and 3rd toes of the hindlimb are slender and united by a fold of skin. The 4th and 5th toes are nearly equal. Hallux is nailless and opposable.

Example: *Trichisurus*.

(2) *Arboreal and clinging*. The members which are arboreal and clinging in habit are usually sluggish and timid. Tail in these forms is vestigial but a cheek pouch is present. Caecum is very large and they lick, instead of drinking. The lateral side of the pouch is extended to form flames. Example: *Phascolarctos* or Koala. The special point about koala is that they are monophagus that is they are adapted to feeding upon the leaves of certain eucalyptus trees and nothing else.

(3) *Flying*. Example of flying marsupial is the flying phalangers or *Petaurus*. Presence of a lateral fold of skin between fore-and hindlimbs enables it to glide.

(4) *Burrowing*. Example is the *Phascolomys* or Wombat. These are relatively large sized and heavily built animals. They are vegetarian and nocturnal in habit. The head is short and flattened. Limbs are thick and short and end in strong claws excepting the hallux. The 2nd and 3rd toes of hindlimb are connected by skin. Tail is short.

(5) *Swift locomotion*. The members of the order Marsupialia that are well known for their swift locomotion and browsing and grazing habits are the Kangaroos (*Macropus*) and Wallabies. They have small head and neck. The forelimbs are smaller than hindlimbs and are with five digits. Hindlimbs are long and powerful. The hallux is absent and syndactyly is present in the hind leg. Marsupium is large. The tail is stout and long and supports the body during rest. The Kangaroos sail across the landscape in graceful, prodigious leaps propelled by their powerful hind legs.

Affinities of Marsupialia

Affinities with Cynodont-like reptiles. The skull of American Opossum is nearer to the construction of the skull of Cynodont-like reptiles. Some similar features are: (1) 'Alisphenoid bulla', (2) 'Epipubic' bone and (3) Stapes.

Affinities with Monotremes Marsupials share many "heritage features" with the monotremes, such as: (1) construction of the brain, (2) structure of the skull and (3) close resemblances between faetal monotremes and the faetal marsupials. Yet monotremes are more primitive than the marsupials in retaining an essentially reptilian pectoral girdle and oviparous in habit.

Affinities with Placentals. Despite close similarities between marsupials and the placentals, there is a set of characters that distinguish the marsupials from the higher mammals, viz. (1) Inflated angular process, (2) jugal extends backwards beneath the zygomatic process of the squamosal to the glenoid fossa, (3) fenestrated bony palate, (4) enlarged 'alisphenoid bulla", (5) inferior arch of the atlas is often incomplete or cartilaginous in the midline, and (6) the head of the astragalus is usually small or narrow and not expanded transversely as in many placentals.

Phylogenetic consideration of Marsupials

A comparison of the biological organisation of marsupials and placentals, reveals that the marsupials appear to be "second-class mammals'. For this reason, it was the common practice for the Zoologists to regard the marsupials as the transitional step in the evolution of mammals between the ancestral Jurassic mammals and the Cenozoic placentals. But the available evidences indicate that the marsupials and placentals have evolved independently from the common panthotherian ancestor in upper Jurassic period and both of them evolved side by side. Fig. 9.35 will give an idea about the phylogenetic relationship of marsupials with the monotremes and placentals.

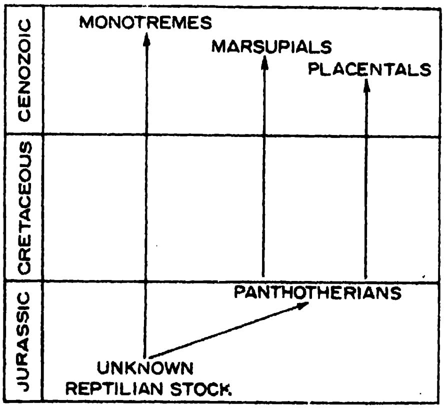

Fig. 9.35. Schematic representation showing the phylogenetic relationship between the three surviving groups of mammals.

Infraclass (*c*) Eutheria or Placentalia.

In Eutherians, the youngs go through a considerable period of pre-natal growth and born as miniature adults. A highly organised allantoic placenta is present. The brain is highly developed. Cerebral hemispheres and cerebellum are well developed. The hemispheres have well developed *neopallial* region. The two hemispheres are connected by corpus callosum. Anterior commissure is ill developed. The ureters pass outside the genital duct in both the sexes. The uteri and vagina show a tendency of becoming single. The anal and urinogenital apertures are separate. Cloaca is absent.

The osteological characters show that the brain case is large and the bony palate is solid. The angle of the lower jaw is not inflected. The tympanic bone is ring-like and forms a tympanic bulla. Alisphenoid is never associated with the bulla. The bulla is perforated by the carotid canal. Dental formula, in general, is $\frac{3.1.4.3}{3.1.4.3}$ but undergoes modifications in different groups and teeth are absent in some forms.

In the post-cranial skeleton, there are seven cervical vertebrae. The thoracic series of vertebrae bear ribs. Ribs are lacking in the lumbar vertebrae. Epipubic bone of the pelvis is absent.

Cohort (*a*) **Unguiculata.** It includes those placentals which possess nails or claws and are derived directly from primitive insectivores.

Order 1. Insectivora.

Insectivores are earliest and primitive of all eutherians. They are believed to be ancestors of all other placental mammals. They are persisting unchanged from Cretaceous period. They are distributed in Asia, Africa, Europe and North America. These small, terrestrial and nocturnal insectivores are stamped with many primitive and some specialised characters. The primitive characters are exhibited by its topical dental formula which is $\frac{3.1.4.3}{3.1.4.3}$.

The skull is constricted in the middle. The zygomatic arch is incomplete. The tympanic bulla is absent. The bony palate is incomplete. Palatine is extended to meet the lacrymal. Teeth have sharp molar cusps. On the ventral side of the vertebral column there are nodules between the vertebrae. Humerus is provided with epicondylar foramen. Pubic symphysis is reduced or absent. Digits in each limb are five in number and are provided with claws. Locomotion is of plantigrade type.

Body is covered with hairs. Hairs on the dorsal side are modified into spines (Hedge hog). Caecum is small or absent. Scrotum is absent and the testes are internal in position. The uterus is of bicornuate type. A sphincter muscle is present around anus and urinogenital aperture. Mammary glands are many and are distributed all along the two milk lines on the ventral surface.

Example: *Sorex* (Shrew), *Talpa* (Mole), *Tupia*, *Erinaceus* (Hedge hog), *Crocidura* (Musk shrew).

Order 2. **Dermoptera**

The Dermopterans evolved along a separate line from the primitive insectivores during Eocene. The present day dermopterans are found in Malay, Phillipines and East Indies. They are herbivorous, tree living and their size is like that of a large squirrel.

The tympanic ring forms the bulla and the lower margin of the external auditory meatus. Lower incisors are combed. The brain is primitive and the optic lobes are not covered by cerebrum. The most important feature is the presence of broad folds of hairy skin extending between the legs and onto the tail with which it glides long distances from one tree to another.

Examples: *Cynocephalus* (*Galeopithecus*) *variegatus* (Fig. 9.36) of East Indies and *C. volans* of Malay and Phillipine.

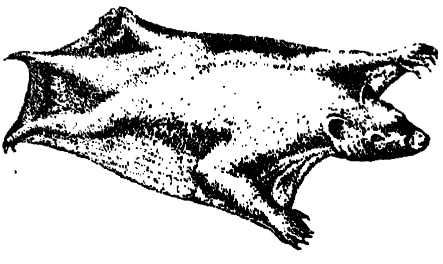

Fig. 9.36. A flying lemur, *Cynocephalus* (=*Galeopithecus*).

Order 3. **Chiroptera**

Members belonging to this order are the only mammals which have mastered true flight like birds. The evolutionary history of Chiroptera is inadequately known. It is believed that they have, at the beginning, undergone through a very rapid evolutionary metamorphosis as the first known bats of Eocene age were little different from their modern relatives. The bats are numerous and their distribution is world wide.

In bats, the forelimbs are modified to form wings. The forelimb bones are elongated, as are all the fingers excepting the pollex for the support of the membrane that runs between fore- and hindlimbs. An interfemoral membrane is present between the femurs. It is supported by a cartilaginous *calcar* of the ankle. A short tail is often included in the interfemoral membrane. The wings are peculiar by having direct arterio-venous connections. The first digit of the forelimb is small, free from the wing and bears a claw. The hindlimbs are weak thus making the bats helpless on ground. The foot has five clawed digits and the bats hang upside down with the hindlimbs.

Pinna is well developed and in many a complicated foliaceous nose folds around the nose is present. Recent experiments have shown that during flight the bats emit a constant stream of supersonic squeaks. The ears catch the echoes or reflections of the sounds from nearby objects and they are being guided by hearing the echoes. Bats are nocturnal but can persue insects ignoring their own sense of vision. The brain has smooth cerebral hemispheres which do not cover the cerebellum. The olfactory region of the brain is ill developed. Only one young is born at a time. The milk set of teeth of the young is hooked which aids in clinging with the body of the mother. The testes are abdominal in position.

Sutures of the skull are obliterated. The postorbital process of the frontal is well developed. Orbital and temporal fossae are confluent. A lacrymal foramen is present outside the orbit. Zygomatic arch is cylindrical. Tympanic bulla is ill developed. Molars have cusps. The ribs are flat and fused with the vertebrae to become rigid during flight.

The clavicle is stout and remains fused with the sternum and scapula. The sternum is provided with a flat keel for the attachment of pectoral muscles. The hindlimbs are rotated so that the knee is directed backward. The cavity of the acetabulum is dorsal in position. Fig. 9.37 gives an idea of the skeletal framework of Fruit bat, *Pteropus*.

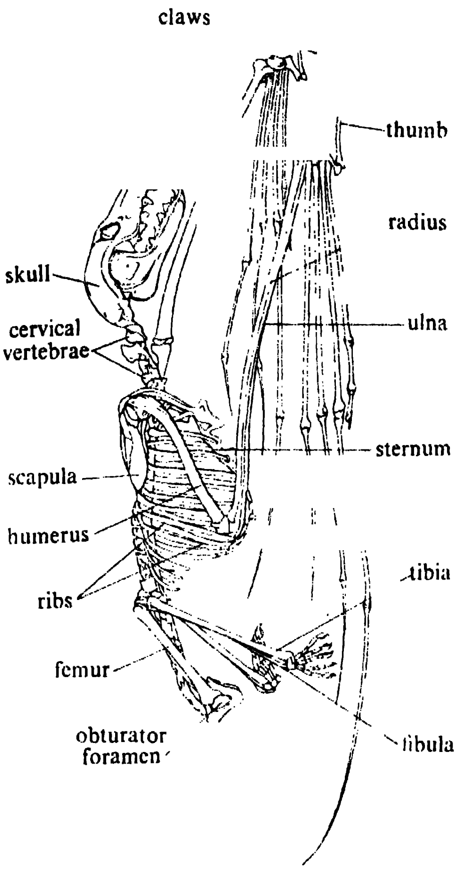

Fig. 9.37. Skeleton of *Pteropus*.

Two suborders: **Megachiroptera** and **Microchiroptera** are included under the order Chiroptera. Besides the common chiropteran features, the suborders differ considerably from each other which are tabulated in Table Chordata—16.

Suborder **Megachiroptera.** They are large in size among the chiropterans and fruigivorous in habit. Eyes are large and snout is elongated. Tail is free from interfemoral membrane. Pinna is simple and leaf-like nasal or auricular appendage is absent. The 2nd digit of the forelimb is provided with claws. Molars are devoid of sharp cusps, but are with longitudinal grooves.

Example: *Pteropus* (Flying fox).

Suborder **Microchiroptera.** The order includes small and insectivorous forms. Eyes are small and snout is short. The first digit of the forelimb is provided with claw. The tail, when present, is enclosed in the interfemoral membrane. The pinna is large and is provided with extra lobe inside called *tragus*. Leaf-like auricular appendage is present. Molars are with sharp cusps and transverse grooves.

Examples: *Vespertilio*, *Rhinolophus* and *Desmodus*. Desmodus is a vampire bat with an extra lobe in stomach.

Order (4) **Primates**

The primates are not so specialised as they are believed to be. The primates have

TABLE CHORDATA—16

COMPARISON BETWEEN MEGACHIROPTERA AND MICROCHIROPTERA

Points	Megachiroptera	Microchiroptera
1. Size	Largest amongst bats.	Smaller.
2. Food habit	Fruigivorous.	Insectivorous.
3. Eyes	Large in size.	Small in size.
4. Snout	Elongated.	Short and blunt.
5. Pinna	Simple and devoid of leaf-like auricular appendages.	Large and with extra lobe called the *tragus*. Leaf-like auricular appendages are present.
6. Tail	Free from interfemoral membrane.	When present, is enclosed in the interfemoral membrane.
7. Claws in forelimb	Both the first and second digits are clawed.	Only the first digit is with a claw.
8. Molars	Devoid of sharp cusps, but possess longitudinal grooves.	Have sharp cusps and transverse grooves.
9. Examples	*Pteropus* (Flying fox).	*Vesperlitio*, *Rhinolophus* and *Desmodus*.

retained many primitive and generalised eutherian characters and at the same time they show specialisation in some respects. The primates are primarily arboreal and return to land as a secondary condition. Primates are omnivorous in habit.

The body is covered over with hairs except the palm, sole and parts of face. The neck is mobile. Forelimbs are shorter than hindlimbs. Limbs have five digits and all the digits end in flat nail. The pollex or thumb, hallux or first toe are smaller than other digits and are opposable (except the hallux of man). Locomotion is of plantigrade type. Tail is present in most forms.

Brain is highly developed. The cerebral hemispheres are enormous, much convoluted and cover the cerebellum. Neopallium and cortex are well formed. Olfactory receptor organs, olfactory bulbs and rhinopallium are drastically reduced. The eyes are directed forward and the vision is binocular and stereoscopic. The face is subcerebral.

Teeth shows reduction in number. Stomach is simple. Caecum is variable in size. Testes lie in scrotal sacs. Mammae are two and thoracic in position. Usually one young is born at a time and parental care is needed for a long period after birth.

The skull is more inclined to the vertebral axis. Orbital ring is complete and the eye-socket is confluent with temporal fossa or is separated by a partition. Foramen magnum faces downward. Zygomatic arch is complete. The tympanic bulla is formed by a flange from the petrosal. The cheek teeth are of *bunodont* type. Clavicle is well developed. Radius and ulna move freely on one another. Lunar and scaphoid are distinct and well developed.

The order Primates includes three sub-orders: Lemuroidea, Tarsioidea and Anthropoidea. The differences between the sub-orders are shown in Table Chordata—17.

TABLE CHORDATA—17

COMPARISON BETWEEN LEMUROIDEA, TARSIOIDEA AND ANTHROPOIDEA

Points	Lemuroidea	Tarsioidea	Anthropoidea
1. Distribution ..	Madagascar, certain parts of Africa and South India.	Phillipine.	Cosmopolitan.
2. Habit ..	Nocturnal.	Nocturnal.	Not usually nocturnal.
3. Hairs ..	Thickly coated.	Thickly coated.	Scanty.
4. Muzzle ..	Elongated and pointed with a *rhinarum* at the tip.	Very short.	Very short.
5. Eyes ..	Laterally placed.	Directed forward.	Directed forward.
6. Pinna ..	Pointed.	Pointed with tuft of hairs.	Rounded.
7. Palmer and planter surfaces	Often with hairs.		
8. Digital tips ..	Provided with flat nail except the second digit of hindlimb.	Bear flat nail except the second and third digits of the hindlimbs. Adhesive discs are present.	Provided with flat nail except the second digit of the hindlimb of Hapalidae.
9. Tail ..	Long, bushy and non-prehensile.	Elongated with a tuft of hairs at the tip. It is non-prehensile.	If present, prehensile.
10. Dental formula	$\frac{2}{2}, \frac{1}{1}, \frac{3}{3}, \frac{3}{3}$.	$\frac{2}{1}, \frac{1}{1}, \frac{3}{3}, \frac{3}{3}$.	$\frac{2}{2}, \frac{1}{1}, \frac{2}{2}, \frac{3}{3}$.
11. Cranial capacity	Small.	Moderate.	Large.

TABLE CHORDATA—17 (contd.)

Points	Lemuroidea	Tarsioidea	Anthropoidea
12. Jugal	Extended backward.	Not so much extended backward.	Not extended at all.
13. Nasal	Broad posteriorly.	Narrower posteriorly.	Narrow posteriorly.
14. Palate	Thickened at the posterior border.	No thickening.	No thickening.
15. Orbital fossa ..	Confluent with temporal fossa.	Communicates with the temporal fossa by a wide fissure.	Separated by a bony partition from the temporal fossa.
16. Lacrymal foramen	Extraorbital.	Extraorbital.	Infraorbital.
17. Mandibular symphysis	Weak.	Fairly developed.	Strongly developed.
18. Sacral vertebrae			4-5
19. Thoracolumbar vertebrae	20-24		16-20
20. Ilia	Narrow and curved outside.	Broad and directed forward.	Broad.
21. Epicondylar foramen	Present.	Present.	Absent.
22. Third trochanter	Present.	Absent.	Absent.
23. Retia mirabilia	Present.	Present.	Absent.
24. Cerebrum	Does not cover the cerebellum.	Does not cover the cerebellum.	Covers the cerebellum.
25. Uterus	Duplex.	Bicornuate.	Simplex.
26. Placenta	Diffused and indecidu-	Metadiscoidal and deciduate.	Metadiscoidal and haemochorial.
27. Urethra	Traverses the clitoris.	Traverses the clitoris.	Clitoris is not traversed by urethra.
28. Sphicter coll	Not developed.	Not developed.	Present and developed to express emotional signs in the face.
29. Examples ..	*Lemur, Loris.*	*Tarsius spectrum.*	New world and old world monkeys.

The suborder Anthropoidea has two divisions under it. The divisions are: Platyrrhina (New world monkeys) and Catarrhina (Old World monkeys). Table Chordata–18 shows the differences between the two divisions.

Evolutionary significance of Primates

The primates include three distinct groups: Lemurs, Tarsioids and Anthropoids. These three groups exhibit an evolutionary sequence from lowly to highly developed condition.

Lemurs occupy the primitive rank. The suborder Lemuroidea shows many distinguishing features which are most primitive. These primitive features are: (1) Low brain-case with its macrosmatic brain and uncovered cerebellum. (2) Backward extension of jugal. (3) Epicondyler foramen in humerus and a third trochanter in femur are present. (4) Laterally placed eyes. (5) Dentition is on the primitive trituberculo-sectorial plan.

TABLE CHORDATA—18

COMPARISON BETWEEN PLATYRRHINA AND CATARRHINA

Points	Platyrrhina	Catarrhina
1. Distribution ..	New World—tropical and neotropical Brazil.	Old world—cosmopolitan.
2. Habit	Arboreal.	Arboreal/terrestrial.
3. Disposition of hair	Usually directed downward.	Variously disposed.
4. Nose ..	Flat, laterally directly.	Pointed, directed downward.
5. Cheek pouch	Absent.	Present.
6. Nail ..	May be claw-like as in Hapalidae.	Flat.
7. Tail ..	Long and prehensile.	May be absent, if present, not prehensile.
8. Forelimbs ..	Almost equal to the hindlimbs.	May be longer than hindlimbs.
9. Size and shape of skull	Usually narrow and small.	Rounded and large.
10. Alisphenoid ..	Meets the parietal.	Does not meet the parietal.
11. Jugal ..	Comes in contact with the post-orbital process of the parietal.	Does not come in contact with the parietal.
12. Tympanic bulla	Well-developed.	Ill-developed.
13. Bony auditory meatus	Ill-developed.	Well-developed and tubular.
14. Auditory ring	Not fused with the skull.	Fused with the skull.
15. Internasal septum	Broad.	Narrow.
16. Thoracolumbar vertebrae	Usually 19–20.	Usually 16–18.
17. Caudal vertebrae	Never less than 14.	Variable.
18. Sigmoid notch	Ill-developed.	Well-developed.
19. Ischial calosities	Absent.	May be present
20. Dentition ..	i$\frac{2}{2}$, c$\frac{1}{1}$, pm$\frac{3}{3}$, m$\frac{3}{3}$ (in Hepalidae m$\frac{2}{2}$).	i.$\frac{2}{2}$, c$\frac{1}{1}$, pm$\frac{2}{2}$, m$\frac{3}{3}$.
21. Number of offsprings	Usually more than one.	Usually one.
22. Examples ..	*Cebus*, *Ateles* (spider monkey), *Alouatta* (howling monkey).	*Macaca* (Rhesus monkey), *Semnopithicus* or *Presbytis* (Langur), *Simia* (Apes), *Hylobates* (Gibbon), *Homo* (Man).

Tarsioids—form the intermediate link. The tarsioids occupy an intermediate position between the lemurs and anthropoids. The lemuroid features are the presence of extraorbital lacrymal foramen and retia mirabilia. But the tarsioids are more advanced than lemurs by having: (1) Forwardly placed eyes. (2) Microsmatic brain. (3) Femur with third trochanter. (4) Jugal does not extend backward.

Anthropoids—occupy the highest rank. The position of anthropoids in the highest rank amongst primates is indisputable, because the anthropoids possess the following characteristics: (1) Forwardly directed stereoscopic eyes. (2) Absence of retia mirabilia. (3) Clitoris is not traversed by urethra. (4) Advanced brain with cerebellum covered by cerebrum. Both have large number of convolutions.

The evolutionary development of the order primates and its phylogenetic relationship with other mammals is far from complete because of the rarity of preservation of the arboreal skeleton. From the scanty fossil evidences and also from the surviving forms, the prime evolutionary trend is the gradual increase in size and complexities of brain, especially the neopallium. The development of brain is largely due to the acquision of an opposable thumb and a grasping hand that enable them to bring the objects before the eyes for examination. .

Order 5. **Tillodontia**

The tillodonts are considered as an 'orphan order' that evolved during Paleocene and Eocene from an insectivore stem and then became extinct. The size was large. They had strong skeleton with heavy and clawed feet. The skull had many similarities with the skull of rodents. The incisor teeth in both upper and lower jaws were large and chisel-shaped. Example: *Tillotherium*.

Order 6. **Taenodontia**

They also are considered as 'orphan order' and are all extinct. They were large animals with a foot or more in length. The limbs were clawed and strongly built. The teeth were long, rootless and were with little enamel. Example: *Stylinodont*.

Order 7. **Edentata**

It is represented by polymorphic and geographically restricted group of mammals. Despite repeated taxonomic rearrangements the true affinities between the different members of the group is not clearly established The edentates excepting the ant eaters possess teeth. Incisors and canines are absent but molars are long and similar in appearance. Enamel and root are absent but the pulp cavity is persistent. A sticky tongue is present. Zygomatic arch is reduced or absent. Clavicle is present but the coracoid and acromion are fused. Ischium is united with anterior caudal vertebrae. Posterior thoracic and lumbar vertebrae are with additional pair of zygapophyses.

Suborder 1. **Palaenodonta** This North American group was an offshoot from the ancestry that gave rise to Xenarthra. They existed between Paleocine and Oligocene.

Metacheiromys of Eocene was about 18 inches in length. In all probabilities they lacked the dermal armour of armadillos but resembled them in finer details. The canines were enamel covered but other teeth were reduced. Ischio-caudal symphysis and extra zygapophyses were absent.

Suborder 2. **Xenarthra** Despite a great diversity of appearance and behaviour the group forms a natural and exclusive group. All the members of Xenarthra belong to South America. Enamel in the teeth is lacking. The zygomatic arch is reduced or absent. Coracoid and acromion are fused. Additional pair of zygapophyses is present on the lumbar vertebrae. Ischio-caudal symphysis is present. Brain is simple and poorly developed. Testes are abdominal. The feet are clawed.

Infraorder (*a*) CINGULATA. Body is covered with horny scutes. Teeth are many. The jugal arch is complete. Many parts of the verteberal column are fused.

Superfamily *Dasypodidae*. The members have small but broad and compressed head. Number of digits in the forelimb varies from 3–5. The digits end in powerful claws. The digits on the hindlimb are 5 in number but the claws are weakly developed. The tail is well developed. An armour of bony dermal plates covers the dorsal part of the body. The armour is divisible into three distinct regions. The anterior part is formed by closely knitted *scapular shield*, the middle part is formed by a series of *transverse bands* separated from one another by hairy skin and the posterior part is formed by a *pelvic shield*. Examples: Armadillos (*Chlamyphorous*, *Tolypeutes*).

Infraorder (*b*) PILOSA. Body is hairy. Teeth are much reduced. Jugal arch is incomplete. Parts of the vertebral column are not fused.

Superfamily *Myrmecophagoidea*. Members are represented by ant-eaters. The mouth is small and snout is elongated. Eyes are small. Forelimb has 5 digits. The 3rd digit is with powerful claw. Toes vary in number from 4–5 and are clawed. Body hairs are long. Tail is long and usually prehensile. Examples: *Myrmecophaga*, *Tamandua*.

Superfamily *Bradypodidae*. Members are with short and round head. Pinna is small. Limbs are long and slender. Forelimbs are larger than hindlimbs. There are three digits in each limb. The digits are provided with long, curved and hook like claws. Arrangement of hairs are opposite of other mammals. Algae grow on hairs to give a protective coloration. Facial part is shorter than cranial part. Teeth are few in number, only 4–5 similar molars on each half of the jaw. Cervical vertebrae are 6–9 in number. Thoraco lumbar are more than 19. Members are nocturnal, vegeterian, arboreal and solitary animal of slow habit. They are found in the rain forests of

North and South America. Examples: *Bradypus* (3 toed sloth), *Choleopus* (2 toed sloth).

Order 8. **Pholidota**

The members of the order were included in the order Edentata. But because of the morphological differences present between them a separate rank has been allotted to them. Most forms under this order are burrowing and terrestrial. They are found in Tropical Africa and Asia. They are primarily ant-eaters.

Body measures about five feet. On the dorsal surface of head, body and tail horny scales are present in an imbricated fashion. Few hairs peep through these scales. The ventral surface is covered with hairs. The eyes are small and pinna is ill developed. The tail is long and tapering. The limbs are short but powerful. There are five digits in each limb. The digits are provided with claws. The claws of the forelimb are curved and sharp. Hindlimb is plantigrade in nature. The facial part is prolonged to form a short muzzle.

The tongue is long, sticky and protrusible and is retained in a sac. Teeth are absent.

The skull is long and cylindrical. The orbital and temporal fossae are not separated. Jugal is reduced. The clavicle is absent. The sternum is provided with cartilaginous rods which extend upto the pelvis. Example: *Manis* (scaly ant-eater or Pangolin).

Cohort (*b*) **Glires.** The cohort includes a large number of forms which were formerly included within the order Rodentia. This cohort is now divided into two order Rodentia and order Lagomorpha. Many adaptive parallels in morphology, physiology and behaviour are present between the members of the two orders. It is believed that the two orders have separate lines of evolutionary sojourn, though both arose from primitive insectivores.

Order 1. **Rodentia**

The order consists of about three thousand species and is numerically the largest of all the mammalian groups. They are global in distribution. Rodents are among the few successful eutherian mammals that thrived well in Australia.

Rodents are small, herbivorous and terrestrial animals. The largest living rodent is Capybara (*Hydrochoerus*) which is about the size of a pig. Beavers, amongst the rodents, are aquatic.

The body of the rodents is covered with soft hairs. Eyes are small but pinna is well developed. The tail is short or long. The forelimbs are smaller than the hindlimbs. Limbs are provided with blunt claws. Locomotion is of plantigrade type.

The brain is small. Cerebral hemispheres are smooth and olfactory lobes are large. Intestine and caecum are large. Jaw muscles are well developed for the purpose of gnawing. Testes are abdominal or inguinal in position. Teats in females are abdominal. The rate of reproduction is rapid and prolific.

The skull is small. Anterior symphysis between the jaws are absent. The premaxilla and maxilla are long for housing the incisors and masseter muscle. The jugal is extended to the glenoid cavity in many forms. Zygomatic arch is complete and tympanic bulla is large. The dentition is modified for chewing and gnawing. There is a single pair of incisors in the upper and lower jaw. The incisors are large, sharp and chisel-shaped. Enamels are absent on the posterior surface of the incisors and as a result they wear off quickly. As the incisors are provided with persistent open roots they grow throughout life. Canine and anterior premolars are absent. A gap called *diastema* is present between incisors and cheek teeth. There are two premolars in the upper jaw and one in the lower jaw. The cusps of the premolars and the molars are joined in transverse fashion.

The scapula is provided with acromion and some time with metacromion process. Clavicles are well developed.

Suborder (*i*) Sciuromorpha. These are primitive forms. Two upper premolars and one lower premolars are present. Infraorbital foramen is not enlarged to transmit any part of the masseter muscle. Examples: *Funambulus* (Squirrel), *Petaurista* (Flying squirrel).

Suborder (*ii*) Theridomyomorpha. They form a separate group of Squirrel like rodents. The infraorbital opening is large but does not transmit any part of the masseter muscle. They are of old world origin and distribution. Examples: *Anomalurus* (West-African flying squirrel), *Pedetes* (Jumping hare).

Suborder (*iii*) Castorimorpha. The sole survivors of the castorimorphs are the beavers. They are aquatic. The feet are, webbed and the tail is covered with scale. Large oil glands are present in the anal region. Example: *Castor* (Beaver).

Suborder (*iv*) Myomorpha. The infraorbital opening is large. The superficial portion of the masseter muscle passes forward in front of the orbit while the median portion passes through orbit. The hindlimbs are longer than forelimbs. Examples: *Mus* (Rat and mice), *Dipus* (Jerboa), *Zapus* (Jumping mouse).

Suborder (*v*) Caviomorpha. It includes New World porcupines. Hairs are modified into quills. Examples: *Cavies*, *Agouti*, *Chinchilla*.

Suborder (*vi*) Hystricomorpha. The infraorbital is enlarged to the greatest extent. The median portion of the masseter muscle is enlarged and is attached to the jugal arch. In some forms, hairs are modified to form quills. Quills on the body are solid but those on the tail are hollow. Examples: *Cavia* (Guinea-pig), *Hystrix* (True porcupine of Asia and Africa).

Suborder (*vii*) Bathyergomorpha. Only one genus of Bathyergomorpha is found in Africa. They are peculiar rodents and are burrowing in habit. The skin is almost devoid of hair. Example: *Heterocephalus* (Naked rat of Africa).

Order 2. **Lagomorpha**

The members belonging to the order Lagomorpha were formerly included in a suborder Duplicidentata under order Rodentia because of superficial similarities. In recent years the Zoologists consider the similarities as the result of convergent evolution. The fossil forms found in the sediments of Paleocene show that the two groups were quite distinct from each other in their early stage of evolution. They are distributed in Eurasia, Africa, North America.

The members belonging to this group are small herbivorous and gnawing forms. Body is covered with soft hairs. Eyes are large and pinna is long. Hindlimbs are larger than the forelimbs. Digits end in claws. The upper lip is provided with a cleft in the middle. The tail is almost vestigial.

The brain is small. Masseter muscles are enormously developed but temporal muscles are weak. Testes lie inside scrotum. Nipples are abdominal in position.

The skull is small. Figs. 9.38 and 9.39 give an idea of the structural organisation of skull and lower jaw of *Oryctolagus*, a typical representative of the order. Anterior symphysis of the lower jaws is present. The orbit is small and muscles never invade the infraorbital canal. Lower jaw articulates with squamosal. Squamosal has large glenoid fossa. The maxillae are laterally fenestrated. There are two pairs of incisors in the upper jaw and one pair in the lower jaw. The incisors of upper jaw are of unequal size. A larger pair lies in front and the

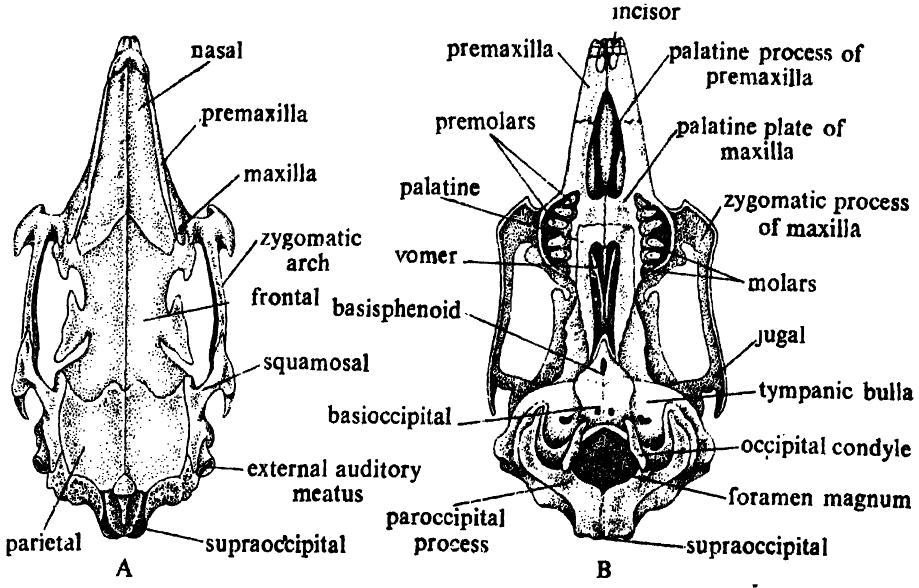
nasal
premaxilla
maxilla
zygomatic arch
frontal
squamosal
external auditory meatus
parietal
supraoccipital
A
incisor
premaxilla
palatine process of premaxilla
premolars
palatine plate of maxilla
palatine
zygomatic process of maxilla
vomer
molars
basisphenoid
jugal
tympanic bulla
basioccipital
occipital condyle
foramen magnum
paroccipital process
supraoccipital
B

Fig. 9.38. Dorsal (A) and Ventral (B) view of the skull of *Oryctolagus*

smaller pair lies behind the front pair. The incisors are chisel-shaped and are covered with thick enamel in the anterior surface and with thin enamel in the ventral surface. They are with persistent pulp. Canines are absent and as such diastema is present. There are three premolars in the upper jaw and two in the lower jaw. Molars are three in number in each jaw. Scapula is with acromian and metacromian processes. Tibia and fibula are fused. Examples: *Oryctolagus* (Rabbit), *Lepus* (Hare), *Pika*.

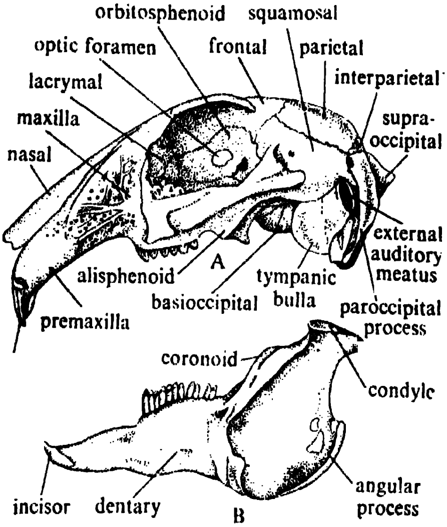
orbitosphenoid
squamosal
optic foramen
frontal
parietal
lacrymal
interparietal
maxilla
supra-occipital
nasal
external auditory meatus
alisphenoid
A
tympanic bulla
basioccipital
paroccipital process
premaxilla
coronoid
condyle
angular process
incisor
dentary
B

Fig. 9.39. Lateral view of skull (A) and lower jaw (B) of *Oryctologus*.

Cohort (*c*) **Mutica.** The cohort includes a single order Cetacea. These are highly specialised mammals and show complete divergence from their primitive eutherian ancestors. The whales are aquatic in all stages of life and because of this peculiar adaptation their affinity with other mammals as well as their phylogenetic history has become obscure.

Order 1. **Cetacea**

The body is large, torpedo-shaped and devoid of hairs. A few sensory bristles are present on the face. The skin is smooth and skin glands are absent. The pinna and nictitating membranes are absent. Finger nails are absent. Hindlimbs are absent. Forelimbs are modified to form the flippers. The nasal openings are asymetrical and located far back on the upper surface of the head. The neck is short. The tail terminates in a horizontal fin that moves up and down. The tail fin called 'fluke' is a neomorphic structure. It is stiff and strong but contains no bone. A fleshy dorsal fin, another neomorph is present on the dorsal side and acts as stabiliser.

A thick subcutaneous layer of fat called *blubber* is present underneath the skin. This acts as heat insulator and reservoir of food. Teeth may be present or absent. Stomach is large and is divided into several chambers (Fig. 9.40). The liver is bilobed. The external nasal aperture can be closed by valves. Epiglottis is tube like. The diaphragm is thick and obliquely placed. The lungs are highly elastic and extensible. Blood vessels are present all over the body and form networks or *Retia mirabilia* specially in the thoracic region for storing extra oxygen to be used when under water. Brain is highly developed. Olfactory lobe is reduced. The scrotum is absent and the testes lie inside the abdomen. The penis when not erected remains curled. The uterus is bicornuate. A single young is born at a time. Gestation period is more than a year. A single pair of mammary glands are located in the inguinal area. The mammary glands are provided with muscles that help secretion. The teats lie in soft pockets. The new borns are usually large and well formed.

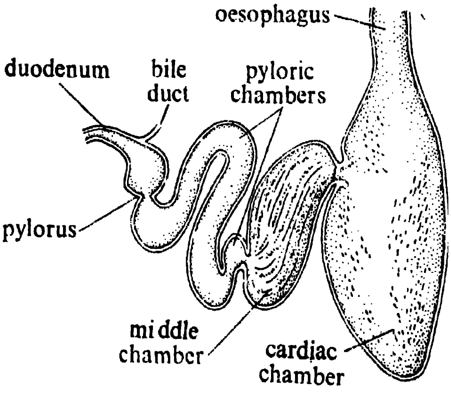
oesophagus
duodenum
bile duct
pyloric chambers
pylorus
middle chamber
cardiac chamber

Fig. 9.40. Diagrammatic sectional view of the stomach of *Phocaena*.

In between the vertebrae and tail, long muscles and tendons are present. These are with much myoglobin.

Fig. 9.41 gives the idea of the skeleton of *Balaena*. In the skull the cranium is dorsoventrally flattened and the facial part is elongated. The jaws are elongated and asymetrical. The parietals are separa-

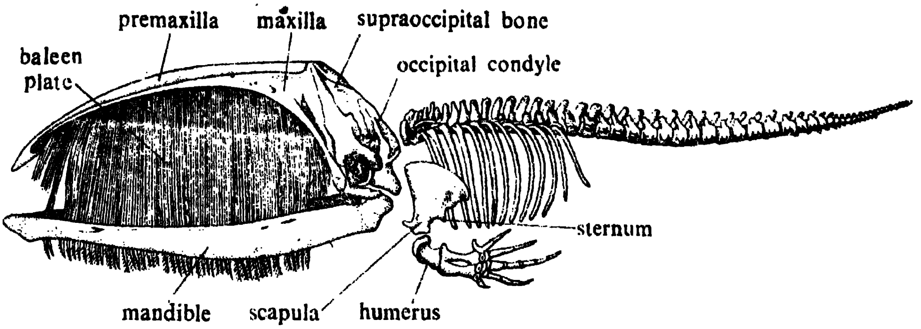

Fig. 9.41. Skeleton of *Balaena*.

ted by supraoccipital and interparietals. The sagittal suture is absent. Zygomatic process of squamosal is large and stout. Jugals are small. Maxilla is large and extends backwards to overlap the frontals. The premaxilla is long and narrow. Nasals are small. Tympanic bone is large. Tympanic bulla is loosely articulated. Ascending ramus in the lower jaw is absent.

The cervical region is very short. Cervical vertebrae are fused to form a bony mass keeping atlas separated. Cervical vertebrae, when remain separated, bear small arches and long transverse processes. Sacral vertebrae are absent. Caudal vertebrae are with chevron bones. Epiphysis remain as separate discs. Zygapophyses are poorly developed or absent. Sternum is much reduced. One pair of ribs articulates with the sternum. Ribs lack heads.

Proximal part of forelimb is embedded in the body. Scapula is broad and fan-shaped. Scapular spine is absent. Acromian is curved. Coracoid is compressed. Clavicle is absent. Humerus is short, stout and its head moves freely in the glenoid cavity. The proximal ends of radius and ulna are firmly united with the humerus. Number of digits are either reduced to four or increased to more than five (hyperdactyly). Number of phalanges is more than usual number in 2nd and 3rd digit (hyperphalangy). Fig. 9.42 shows the hyperphalangy of the forelimb of dolphin, *Globicephala*. The vestiges of pelvis remain as a pair of long narrow bones lying parallel to the spinal column a little below the region where chevron bones begin. Vestiges of femur and tibia are often encountered.

Suborder (*i*) Archaeoceti. This suborder includes primitive or first whales, the fossil forms of which have been found in the sediments of mid-eocene. They were large attaining a length of about 60 feet. The tail was very large. The forelimbs were modified into paddles. The hindlimbs were ill developed. The skull was more primitive than that of latter whales. The facial bones were not telescoped into the back of the skull. The teeth were 44 in number. The incisors and canines were simple and sharp. The cheek teeth were cusped and the cusps were arranged in a single line. The nostrils were located in a forward position and not on the top of the skull as they are now. All are extinct. Examples: *Protocetus*, *Eocetus*, *Basilosaurus* (*Zeuglodon*).

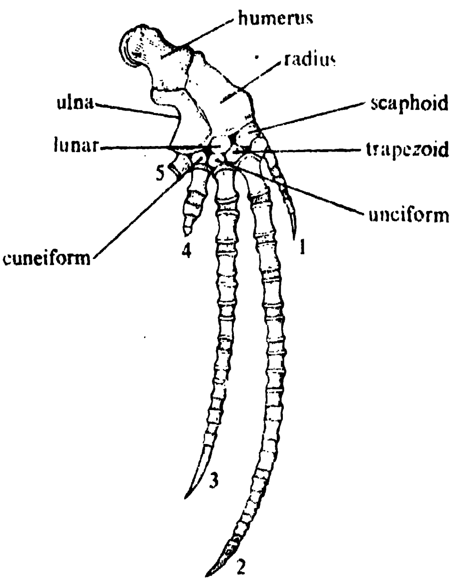

Fig. 9.42. Forelimb of *Globicephala* showing hyperphalangy.

Suborder (*ii*) Odontoceti. It includes toothed whales. The members may be fresh water and marine. The fresh water forms retain many primitive characters. The cervical vertebrae in them are not fused. The interlocking processes of the thoracic vertebrae are more prominent. There are many double-headed ribs. They bear a fairly long beak with sharp homodont teeth on both the jaws. The eyes are rudimentary. External nostrils are united to form a single hole. The nipples in the females lie close to the anus. The dorsal fin is represented by a ridge. The head is round and the skull bears a bony process called *maxillary crest*. Hyperphalangy and hyperdactyly are absent. Size is smaller in fresh water forms.

The marine forms are usually larger in size. The head is large and swollen at the anterior to form a rostrum. The rostrum contains a valuable whale oil called *spermaceti*. The lower jaw is long, narrow and bear teeth. The upper jaw bone is wide posteriorly and lies above the frontal bones. Teeth in the upper jaw are vestigial. The maxillae and nasals are unequal in size. Anterior ribs have capitulum and tuberculum. Sternum is divided into sternibrae. All seven cervical vertebrae are fused together. Secretion of the intestine forms a stone like *ambergris*. Examples: *Phocaena* (Porpoise), *Platanista* (Dolphin), *Orcimus* (Killer whale), *Physeter* (Sperm whale).

Suborder (*iii*) Mysticeti. The order includes those whales which are toothless in adult stage. Teeth are replaced by more than 300 triangular plates or *baleen* (See Fig. 9.41). The baleen is made up of horny structures and hangs from the roof of the mouth and its free end is fringed. The baleen is arranged in two rows one on either side of the upper jaw. Blubber is thin. The tongue is muscular. The dorsal fin is small and is situated far back. The skull is symmetrical and the nostrils are paired. The sternum is not divided into sternibrae. Ribs are single headed. Cervical vertebrae are usually fused. Examples: *Balenoptera* (Blue whale), *Megaptera* (Hump back whale), *Caparea* (Pigmy whale).

Cohort (*d*) **Ferungulata.** A large number of mammals which are both herbivorous and carnivorous in habit are included in this cohort. The inclusion of carnivorous and hoofed mammals under one head may appear strange but palaeontological evidences show that both of them arose from a common mammalian stalk during Pliocene period.

Order 1. **Carnivora**

This order includes the strongest and most formidable of all the terrestrial mammals. They are endowed with proclivities of a violent nature and organised for slaughter and carnage. They form a well-diversified group and show a wide range of adaptive radiation. Most carnivores are terrestrial but some forms are aquatic. Terrestrial forms have strongly built limbs. In aquatic forms, the distal part is modified into paddles and hindlimbs are directed backward. Number of digits in the limbs are usually five but never less than four. Digits end in sharp claws and claws may be retractile. Locomotion is digitigrade or plantigrade.

Brain is highly developed. Intelligence in the form of mental alertness and coordinated actions is present. Sense of smell is well developed. Dentition is highly specialised and characteristic. Intestine is short and caecum is small or absent. Scrotal sac is present. Mammae are abdominal in position. Uterus is bicornuate. Placenta is deciduate and zonary.

The skull is short and high. Sagittal and lambdoidal crests are well developed. Zygomatic arch is strongly built. The temporal fossa is deep. Glenoid fossa is transverse. The tympanic bulla is large and rounded.

The cavity of the bulla is separated into an anterior and a posterior part by a septum. The posterior part of the bulla is often associated with a paroccipital process. Three pairs of incisors are present both in the upper and lower jaws. Canines are sharp and pointed. The last upper premolar and first lower molar have become transformed into blades that act against each other like the blades of a pair of scissors. They are jointly known as *carnassial* teeth. Fig. 9.43 shows the carnassial teeth in different carnivores. The last two molars in each jaw act as crushing teeth.

The atlas is large and is provided with wing like lateral processes. The neural spine of the axis is long and compressed and the odontoid process is conical. Cervical vertebrae are with small spine and long transverse processes. Thoracolumbar vertebrae are 20 or 21. Anterior thoracics are with slender but backwardly directed spines. Posterior thoracics bear well developed metapophyses and anapophyses. Lumbar vertebrae have short spine and long transverse processes. The sternum is long, narrow and is made up of 8 or 9 sternibrae. Sternal ribs are not calcified. The clavicles are reduced. In the wrist, *scaphoid*, *lunar* and *centrale* are fused. This order includes three suborders: Creodontia, Fissipedia and Pinnipedia. The order Creodontia includes the extinct forms.

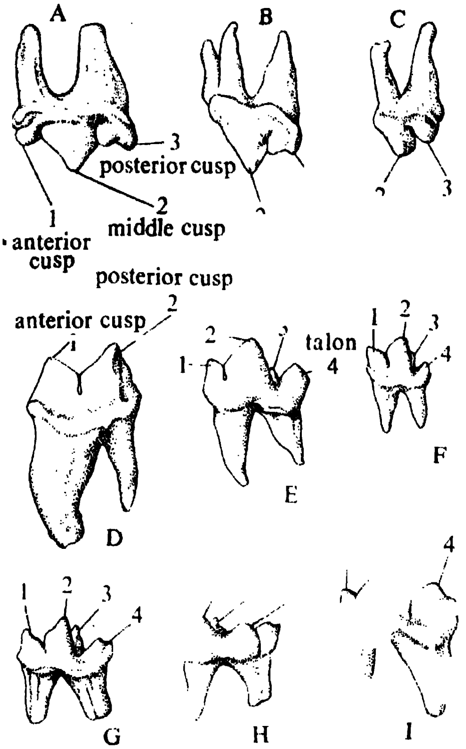
A
B
C
3
posterior cusp
2
1
anterior cusp
middle cusp
3
posterior cusp
anterior cusp
2
1
2
3
talon
4
1
1 2 3
4
D
E
F
1 2 3
4
4
G
H
I

Fig. 9.43. Carnassial teeth of different carnivores. A–C. Upper carnassials of *Felis* (A), *Canis* (B), *Ursus* (C). D–I. Lower carnassials of *Felis* (D), *Canis* (E), *Herpestes* (F), *Lutra* (G), *Meles* (H), *Ursus* (I).

Suborder (i) **Creodonta.** The suborder includes extinct members which were very dominant flesh eaters of Pliocene. The members were moderate in size. The limbs and the body were long and slender. The limbs were pentadactylous and digitigrade. Brain was poorly developed and the skull arch was low. The dentition was complete. Carnassial teeth were still to appear. It is believed that from this centralised and unspecialised assembly diverse modern carnivores have evolved which lived until Oligocene. Examples: *Tricentes*, *Claenodon*, *Arctocyon*.

Suborder (*ii*) Fissipedia. Terrestrial members of the order Carnivora are included in this suborder. On the basis of anatomical characters such as structure of the auditory bulla, presence or absence of alisphenoid and the pattern of molar teeth, the suborder has been divided into two super families.

Superfamily: Canoidea or Arctoidea

The tympanic bulla is not partitioned or partition is incomplete. Paroccipital process is small or absent. Dentition in most forms is $\frac{3.1.4.2.}{3.1.4.3.}$

There are five families of which one is extinct.

Family: *Miacidae* (Extinct).

Family *Cancidae*. Distribution is universal excepting Australia, New Zealand and Madagascar. The limbs are long. Forelimbs are with 4 or 5 digits. Hindlimbs are always with 4 digits. Pollex and hallux are reduced. Claws are non-retractile and locomotion is digitigrade. Carnassials are well developed. Last upper premolar is absent. Fig. 9.44 shows the organisation of skull and lower jaw of a typical carnivore, *Canis*.

Examples: *Canis* (dog), *Vulpes* (fox), *Cyon* (wild dog).

Family *Mustelidae*. Members are slender bodied, long necked but short legged forms. Claws are non-retractile. In semi-aquatic Otter the digits are webbed. Carnassial teeth are well developed. Last upper molar is expanded. Tympanic bulla is not inflated and internal septum is absent

Examples: *Lutra* (Otter), *Meles* (Badger), *Mustella*. (Weasels).

Family *Ursidae* Members are large. Body is covered over with coarse hair. Limbs are with five digits and

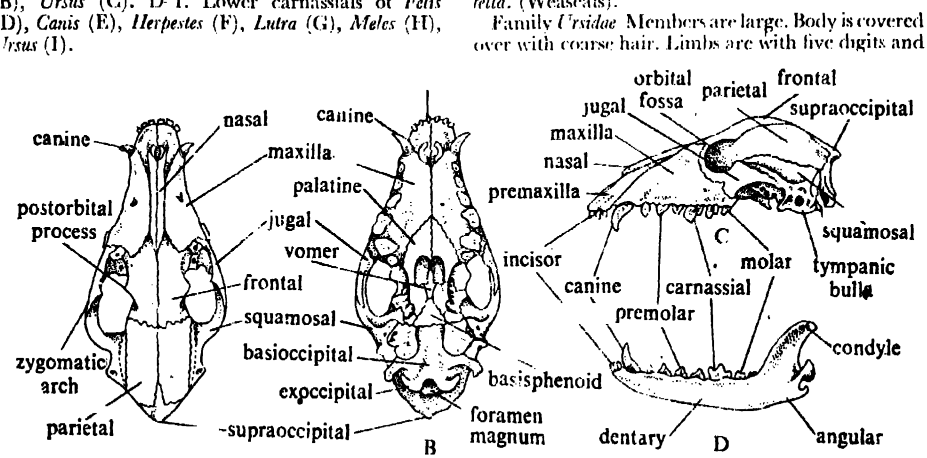
canine
nasal
postorbital process
zygomatic arch
parietal
canine
maxilla
palatine
jugal
vomer
frontal
squamosal
basioccipital
exoccipital
supraoccipital
B
foramen magnum
basisphenoid
orbital fossa
parietal
frontal
jugal
supraoccipital
maxilla
nasal
premaxilla
C
squamosal
incisor
molar
tympanic bulla
canine
carnassial
premolar
condyle
dentary
D
angular

Fig. 9.44. Dorsal (A), ventral (B) and lateral (C) view of skull. D. Lateral view of lower jaw of *Cani*.

digits are clawed. Locomotion is plantigrade. Tail is short. The tympanic bulla is flat. Carnassial teeth are not formed. Molars are large, elongated and much tuberculated. The last molar is reduced. Members undergo hibernation.

Example: Ursus (Bear).

Family *Procyonidae*. Distribution is America, excepting the Panda which is oriental. The claws are not retractile. The first premolar and last molar are absent. Carnassial teeth are absent. The upper molars are round in shape.

Examples: *Procyon* (Racoon), *Ailurus* (Panda), *Potos* (Kinkajou, Carnivore with a prehensile tail).

Superfamily: Feloidea. The tympanic bulla is divided by a complete septum into anterior and posterior chamber. Paroccipital process remains in close contact with the bulla. Dentition is $\frac{3.1.3.1.}{3.1.2.1}$ Carnassials are well-developed. Premolars and molars are reduced in size. Locomotion is digitigrade. It is divided into three families.

Family *Viverridae*. The members are found in Asia and Africa. Members possess short pinna and legs. Digits have non-retractile claws. The skull is large and dentition is typical.

Examples: *Viverricula* (Civet), *Herpestes* (Mongoose).

Family *Hyaenidae*. The members are found in Asia and Africa. The anterior part of the body is massive and slants posteriorly. Body is stripped and the pinna is large. The number of digits in each limb is four. Digits end in non-retractile claws. Carnassial teeth are well-developed. There is one molar in each jaw and the upper molar is vestigial. The tympanic bulla is partially divided by a rudimentary internal septum.

Example: *Hyaena*.

Family *Felidae*. The members are distributed widely though most members are found in the tropics. They are absent in Australia and Madagascar. The members are very active predators. Body is large. Eyes and pinnae are large. Tail is long. The digits end in claws and the claws are retractile. Pads are present beneath the digits. Skull is very strongly built. Carnassial teeth are well-developed. Premolars are reduced in size and number. There are three premolars in the upper jaw and two on the lower jaw. Molars are reduced.

Examples: *Felis domesticus* (Cat), *Panthera leo* (Lion), *Panthera tigris* (Tiger).

Suborder (*iii*) Pinnipedia. Members belonging to this suborder are marine but they come up on land to give birth to youngs. The body is streamlined and is covered with soft hairs. In Seals, hair is present on palm and sole. Tail is short. Eyes are directed upwards. Nostrils are provided with valves. Penis is provided with a bone. Folds of skin cover the genitalia and nipples. Limbs are modified to form paddles. Hind paddles are directed backwards. Retia mirabilia are present. This suborder differs widely from the suborder Fissipedia which are tabulated in Table Chordata-19.

TABLE CHORDATA—19

COMPARISON BETWEEN FISSIPEDIA AND PINNIPEDIA

Points	Fissipedia	Pinnipedia
Distribution	Cosmopolitan.	Temperate and Arctic zones.
Habit	Terrestrial.	Secondarily aquatic.
3. Digits	Usually four, never less than four.	Always five, bounded by web. Hyperphalangy is observed.
4. Claws	Present.	May be absent.
Size of pollex and hallux	Smaller than the rest.	Larger than the rest.
Pinna	Well-developed.	Ill-developed or absent.
Skull ..	Usually elongated with highly developed crests.	Usually broad and rounded with ill-developed crests.
Orbital constriction	Ill-developed.	Well-developed.
9. Palate	Broad.	Narrow.
10. Vertebral column	Well-differentiated into different regions.	Short and compact.
11. Scapula ..	Scapular spine and acromian process are well-developed.	Not so much developed.

TABLE CHORDATA—19 (contd.)

Points	Fissipedia	Pinnipedia
12. Clavicle ..	Usually present, though ill-developed.	Usually absent.
13. Limb bones ..	Elongated and well-formed.	Short and compact.
14. End of radius and ulna	Rounded.	Flattened.
15. Third trochanter	Ill-developed or absent.	Well-marked.
16. Incisors ..	$\frac{3}{3}$	[illegible]
17. Canines ..	Well-developed and sharp ..	Ill-developed.
18. Carnassial teeth	Well-developed.	Absent.
19. Molars ..	Pointed.	Usually flattened.
20. Testes	May be abdominal or scrotal.	Always scrotal.
21. Mammary glands	Many pairs.	One or two pairs.
Youngs	Dependent.	Independent.

The suborder Pinnipedia includes three families. *Ottariedae*, *Odobenidae* and *Phocidae*. Fig. 9.45 showing the skeleton of Seal, *Phoca* to give the skeletal organisation of Pinnipedia in general. In the first two, the hind foot is used in locomotion on land. The forelimbs are used in swimming. In the third family the hindlimbs are attached with a fold of skin along with the tail and the hindlimbs are used in swimming. The pinna in otteridae is provided with a cartilage and hence the name. In Walruses, the upper cannines become large to form tusks in both the sexes.

Examples: Ottariedae Otter (sea-lions and fur-seals), *Odobenus* (Walrus), *Phoca* (Seal).

Order 2. **Condylartha.**

This order resembled the creodonts in some respects and at the same time foreshadowed the hooves. They were omnivorous and nod-predaceous animals. The tooth pattern was different from creodonts. Shortening of jaws or reduction of incisors never appeared. The astragalus was of creodont carnivore type and the interlocking of carpus with centrale was quite evident. The third toe showed a tendency to become larger and *paraxonic*. They persisted from Paleocene to Eocene period.

Examples *Meniscotherium*, *Phenocodus*.

Order 3. **Litopterna**

The order includes a number of individuals, some of which were half made horses and the others were half-made camels. They evolved in South America in Paleocene period and continued through Pleistocene epoch to become extinct. The skull was elongated and low and the nasal openings were situated far back on the upper surface of the skull. A

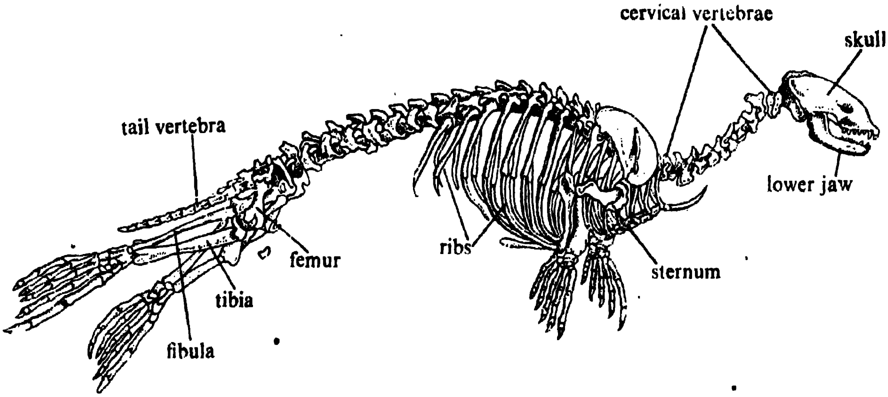

Fig. 9.45. Skeleton of *Phoca*.

postorbital bar kept the eyes separated from the temporal region. The incisors were chisel-shaped. The cheek teeth were *selenodont* type. Premolars tended to become molariform. The vertebral column was straight. The limbs were slender. The hind feet had three digits. Of those the middle was large and hoofed. The lateral toes were reduced.

Examples. *Diadiaphorus*, *Thoatherium*.

Order 4. **Notoungulata**

Fossil forms of this order have been discovered from Mongolia, North America and South America. It is believed that they were Asiatic in origin and migration to North American took place during Tertiary age through Berring strait. The members were primitive, small and hoofed. The skull and the jaws were heavily built. The postorbital process was not present. Zygomatic arch was very strong. The dentition was of uniform pattern from anterior to posterior. Canines lost their typical shape. Molars were *lophodont* type.

Examples. *Palaeostylops*, *Arcostylops*.

Order 5. **Astrapotheria**

This was an order which persisted in South America from Eocene to Miocene period. A trend to gigantism was exhibited by the members. The skull and jaws had peculiar modifications. The front of the skull was short. The nasal bones were small and retracted in position suggesting the presence of a proboscis. Upper incisor was absent. The upper canines were greatly enlarged and they were like downwardly directed daggers. The lower jaw was elongated. Lower insisors were present. The lower canines were large. It is believed that a long and tough upper lip was present between the retracted front portion of the skull and the front of the lower jaw. Example: *Astrapotherium*.

Order 6 **Tubulidentata**

The order is represented by a single genus and found only in Africa. The body is strongly built. Hairs on the body are few in number. The colour of the body is dull-gray. The head is elongated to form a tubular snout. Pinna is long. Limbs are strong. The forelimbs are with four digits which end in claws. The hindlimbs are provided with five clawed digits. Mouth is small. The tongue is long and protrusible. Incisors and canines are absent. The cheek teeth are 4 or 5 in number. They lack enamel but a coating of cement is present. When viewed under microscope the dentine appears tubular and hence the name of the order. They are anteaters and the relationship is problematical. Example: *Orycteropus* (Aardvarks).

Order 7. **Pantodonta**

The order is represented by few forms which evolved during Paleocene and became extinct in Oligocene. The members were sheep like in size during the early phase of their evolution. In the later phase there was an increase in size. The skull was long but low. The canines were large and the upper molars were triangular in shape. The limbs were heavy and short. The hind limb had five digits, each terminated into a hoof. Example: *Pantolambda*.

Order 8. **Dinocerata**

Fossil forms of the members of this order have been discovered from North America and Asia. They were evolved in Paleocene and became extinct in Oligocene. The body was large and heavy. The upper limb elements were long while the lower limb elements were short. The feet were broad and spreading. The skull was low. The front of the lower jaw was deeply flanged. The canines were long. Example: *Prodinoceras*.

Order 9. **Xenungulata**

This order has recently been established and is based on the characters of a single genus obtained from Pliocene sediments of Brazil and Patagonia. The size was large. The limbs were short. Foot was broad and five-toed. The dentition was complete. Incisors were chisel-shaped, canines were strong. Premolars were pointed and molars were cross-crested. Scanty fossil remains have not yet furnished further information about the shape of the skull or other anatomical features. Example: *Carodnia*.

Order 10. **Pyrotheria**

A small and isolated group of South American ungulates is included in this order. They evolved during Pliocene and became extinct in Oligocene. They were gigantic in size and had many proboscidian features. The skull was large and the nasals were retracted indicating the presence of a trunk there. The zygomatic arch was strong and heavy. The back portion or ascending ramus of the lower jaw was large. Two of the upper incisors on each side were enlarged to form the tusks. In the lower jaw, there was a single tusk-like incisor. Canines were absent on either side. The cheek teeth were low crowned. Because of their similarities with Proboscidea they are considered to be proboscidean relatives. Modern opinion regards them as independent order of mammals. Example: *Pyrotherium*.

Order 11. **Proboscidea**

The members belonging to this order are represented by an isolated group. At an early stage in their phylogeny they aquired a number of peculiar and adaptive characters which distinguished them from other mammals. They are stamped with primitive and specialised characters.

The body is huge. They are largest of living land vertebrates. Skin is thick and hairs are scanty. The fusion and elongation of the nose and upper lip have resulted in the formation of a large prehensile trunk (Fig. 9.46 A, B). The nostrils are situated at the tip of the trunk. The eyes are small and the pinna is large. The tail is flat. The limbs are pillar-like and pentadactylous. The digits are short, stout and are united by skin. Each digit is provided with a small hoof and the back of the digits are supported by a pad of tissue. Locomotion is of digitigrade type.

The cerebral hemispheres are convoluted but do not cover the cerebellum. The precavals are paired. The stomach is simple. The intestine is long and caecum is large.

Testis is abdominal in position. A pair of pectoral mammae is present. Only one young is born at a time after a gestation period of 22 months. Head gland is located in the temporal region of the males.

The skull is massive. Sutures of the skull are obliterated. The facial and nasal parts are reduced. Frontal and parietals are separated. Skull bones are with '*diploe*' or *air cells* (Fig. 9.46C). Dentition is highly characteristic. There is a single pair of incisors in the upper jaw. Incisors are absent in the lower jaw. The upper incisors have no root and they grow to form tusk. The tusks are made of ivory which is a specialised dentine. Enamel remains as a small cap on the tusk for a short time and then wears off. Premolars and canines are absent. In the adults, three molars are present in each half of the upper and lower jaws. The molars consist of a number of deep plates of enamel covered dentine bound together by cement (Fig. 9.46 D, E). Not more than two molars remain functional at a time. In cases of wearing off, the third dormant molar comes up and replaces the worn out teeth. The cervical region is short. Thoracic vertebrae are with high neural spine. Ribs are 20 in number. Clavicle is absent. Radius and ulna are crossed. Carpus is larger than radius and is articulated with ulna. The pelvis has broad ilia and it is vertical in direction. Tibia and fibula are distinct. The carpals and tarsals are serial and compressed. Examples: *Elephas* (Indian elephant), *Loxodonta* (African elephant).

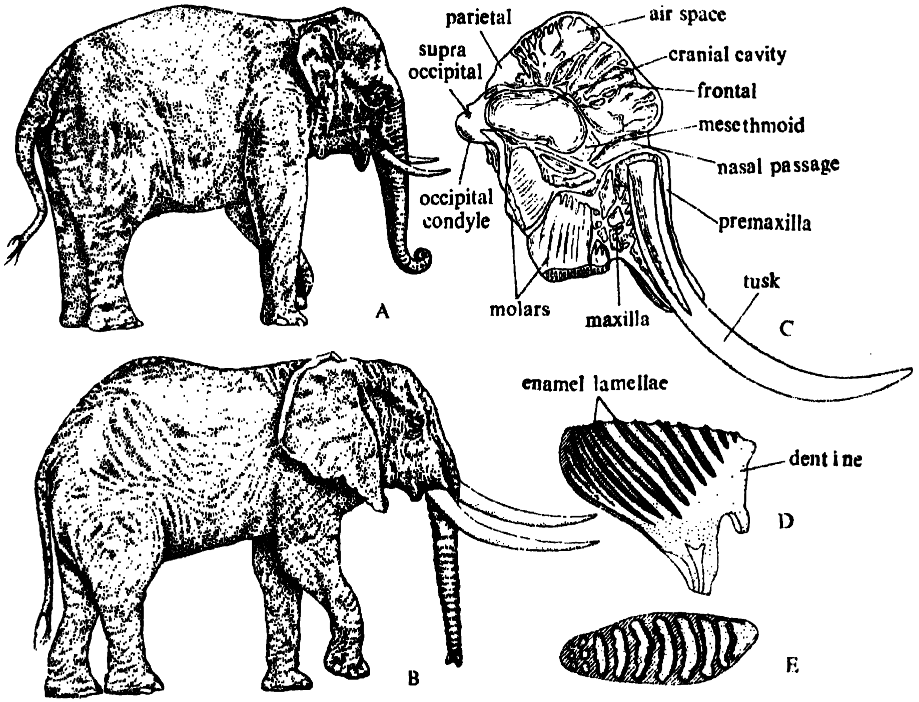

Fig. 9.46. Two surviving genera of elephants. A. *Elephas*. B. *Loxodonta*. C. Sagittal section of skull of *Elephas*.

Order 12. **Embrithopoda**

The order is represented by a single genus which appeared in Oligocene in Egypt. Nothing is known about its ancestors or descendants. They were large as big as rhinoceros. Limbs were elephant like. Feet were broad and spreading. A pair of massive and bony horns were present. The base of the horn was extended between the nostril and cranium. The skeleton was heavy. The skull was large and the teeth formed a continuous series from incisors to last premolars. The cheek teeth were long crowned. Example: *Arsinotherium*.

Order 13. **Hyracoidea**

In Hyracoidea there is a peculiar admixture of primitive and specialised characters and they resemble different orders of mammals. They are found in Africa, Arabia and Syria.

They are small rabbit like in size. Snout is splitted in some forms. Pinna is short. Tail is short. Locomotion is plantigrade. There are four digits in the forelimb and the fifth one remains as a vestige. Hindlimbs are provided with three digits. The digits end in hoofs except the second digit of the foot which is clawed.

The stomach is constricted in the middle. Gall bladder is absent. The caecum has a pair of caecal pouches. Testes are abdominal. A single pair of pectoral mammae are present. Uterus is paired.

The skull is with peculiar features. The postorbital bar arises from the parietal. This bar is complete in some forms. The jugal is stout and extends backward to take part in the formation of glenoid cavity. The periotic and tympanic bones are united together and not with the squamosal. The tympanic forms a bulla and has a spout like external auditory meatus. The seventh cervical vertebra may be pierced by the vertebral artery. Thoracolumbar vertebrae are 22 in number. Scapula is triangular and is without an acromian. The clavicle is absent. The radius and ulna are crossed. Centrale persists in the carpus. Astragalus is different from all other mammals.

A single pair of large and curved upper incisors with persistent root is present. Canines are absent. The lower jaw bears two pairs of incisors which are comb like. There are 4 premolars and 3 molars. They are lophodont and are all alike. Examples: *Hyrax* (coney), *Dendrohyrax*.

Order 14. **Desmostyliformes**

The order constitutes a very interesting group of Oligocene mammals. Their fossil remains have discovered very recently along both the sides of the Pacific ocean.

They were large bodied animals. Limbs were heavy and elephant-like in construction. The skull resembled that of mastodonts. Tusks were present. The nasal opening was retracted suggesting the presence of a trunk. The check teeth consisted of vertical columns arranged in pairs along their length.

These mammals form a sort of "marine hippopotamus" which used to swim in shallow water in the sea coast. The members show anatomical similarities with the sea-cows in one hand and the elephants on the other. To all probabilities they are truly intermediate forms. Example: *Desmostylus*.

Order 15. **Sirenia**

The members belonging to this order are probably early offshoot from the line of proboscidian evolution. Because of their aquatic adaptation they have in their bodies many features that are similar to that of Cetaceans. But these similarities are due mainly to the convergent evolution.

Members belonging to this order are either fresh water or marine and are found along the coasts of America, Africa, Indian ocean, South Pacific and Australia. They are large herbivorous animals but they do not go to the open sea.

The body is large and streamlined. Muzzle is round and the upper lip is protruding. The neck is short. Nostrils are located on the upper surface of head and are provided with valves. Pinna is absent. Eyes are small with muscular eyelids. Hindlimbs are absent. Forelimbs are modified into paddles. There are 5 digits in the forelimbs and the digits are webbed and nail less. Tail is round or rhomboidal in outline. Hairs on the body are almost absent.

A thick layer of fat called blubber is present beneath skin. The intestine is long. Diaphragm is oblique in position and highly muscular. Lungs are elongated and air sacs are associated with them. Retia mirabilia are present. Testes are abdominal. The mammae are pectoral in position and lie in skin pockets. Brain is small and ventricles are comparatively large.

Fig. 9.47 shows the skeleton a typical form, 'Sea Cow' of the order. The skull bones are hard and compact. The cranial cavity is long and narrow. The supraoccipital extends forward but does not separate the parietals. Broad supraorbital plates develop from the frontals. The zygomatic arch is strong. The nasal bones are vestigial. Tympanic and periotic bones can be easily separated from other bones. Tympanic bone is ring shaped. Premaxilla is large in dugongs. The ascending ramus of the mandible is well developed. Coronoid process is also well developed.

The cervical vertebrae are not ankylosed. Number of cervical vertebrae in manatee is only 6 and the neural arches are sometimes incomplete. The trunk and thoracic vertebrae are more than the usual number with well developed zygapophyses. Facets in them are well developed for articulation with rib heads. Caudal vertebrae are numerous, fattened and are with wide transverse processes. Sternum is not divided into sternibrae. Ribs are many but are not connected with the sternum. Sacrum

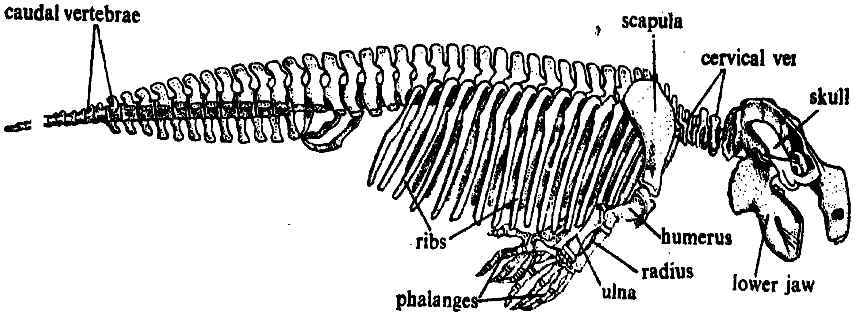

Fig. 9.47. Skeleton of *Dugong*.

is absent. Dentition is characteristic. In Manatus there are up to twenty cheek teeth in each half of the jaws. They are covered with enamel and are lophodont. All are not used at a time and they are always in the process of replacement from the hind end. In dugong the teeth are reduced. The cheek teeth are never more than six and are degenerated.

The scapula is narrow and curved backwards. Scapular spine is located in the middle. Acromian is directed downwards. Coracoid is conical in shape and well developed. Clavicle is absent. The radius and ulna are fused at their extremities. Carpus is composed of seven bones in Manatee. The pisiform bone is absent. In dugong carpals are fused. The five digits possess usual number of phalanges. Hyperdactyly or Hyperphalangy is absent. The pelvis is vestigial and is without any connection with spinal column. The vertical position and rod-like shape suggest that it represents the ilia. Examples: *Halicore*, *Manatus*, *Rhytina*.

Comparison between Cetacea and Sirenia.

The whales and 'sea-cows' are included under the order Cetacea and Sirenia respectively. Although both the orders are phylogenetically far apart, they exhibit striking structural and physiological similarities. These similarities are due their *adaptive convergence* for living in aquatic medium. They have become 'fish-like' in appearan and have abandoned many typical mammalia features like, hairs, integumentary glands, etc. Despite such unique resemblances they show many differences, specially in the construction of skull and in the orientation and nature of dental battery. The differences are shown in Table Chordata—20.

TABLE CHORDATA—20

POINTS	CETACEA	SIRENIA
1. Size	Some attain a colossal size.	Comparatively small.
2. Habitat	Marine forms. Larger species prefer open sea, while smaller forms live near coast and may ascend the rivers.	Live in sea near coast, also available in plenty in estuaries and river.
3. Habit	Carnivorous and predaceous animals.	Herbivorous and feed on aquatic vegetation.
4. Hairs	Absent, except a few bristles around the muzzle which may be also absent in many whales.	Very sparse.
5. Caudal fin	Horizontally expanded which is usually divided into 'flukes'.	Horizontally flattened, either rounded or rhomboidal in outline.
6. Dorsal fin	An adipose dorsal fin is present.	Absent.
7. Eyes	Small and devoid of third eyelid.	Small and have third eyelid.

TABLE CHORDATA--20 (contd.

POINTS	CETACEA	SIRENIA
8. Nostrils	Nasal aperture is present on the forehead as the single or double blowhole, usually shifted to the dorsal side of the head. Valvular arrangement is highly developed.	Separate from one another and placed on the front of the head. Valves and pads are less developed.
9. Mammae	Inguinal in position.	Pectoral in position, close behind the forelimbs.
10. Hindlimbs	Mostly absent, vestige may be in foetus.	Usually absent.
11. Forelimbs	Short and transform into paddles. Externally unjointed and covered by skin. Lack movable joints. Number of digits—usually 5, may be 4 as in *Balaena*. Hyperphalangy and hyperdactyly are present. Usually having no trace of claws.	Short and transform into flippers—enclosed by a common cutaceous covering. Movable joints are present. Number of digits-5. Hyperphalangy and hyperdactyly are absent.
12. Teeth	Sometimes absent, if present, are conical, homodont, monophyodont and numerous. May be absent in Whale-bone whales.	Variable. *Rhytina* has no teeth, *Halicore* has rootless and enamelless molars, *Manatus* possesses numerous molars and no incisors.
13. Salivary glands	Absent.	Well-developed.
14. Stomach	Divided into three chambers.	Not divided.
15. Intestine	Moderate in length.	Very longated with large caecum.
16. Trachea	Very short with a third bronchus.	Short and having only two bronchi.
17. Epiglottis and arytenoid cartilage	Prolonged into nasal passage.	Not prolonged.
18. Lungs	Spacious—not lobed.	Elongated with associated air-sacs.
19. Diaphragm	Oblique and less muscular.	Oblique and highly muscular.
20. Brain	Large with much convolutions.	Small with slight convolutions.
21. Placenta	Zonary.	Diffused.
22. Bones	Spongy and contain oils.	Heavy and compact as an adaptation to take submerged weeds from the bottom.
23. Vertebral column	Epiphyses are distinct. Cervical vertebrae are seven in number, more or less fused with one another and are disc-like appearance.	Epiphyses absent. Cervical vertebrae may be six (as in *Manatus*)—compressed, but ankylosed, neural arches may be incomplete.
24. Sternum	Short.	Usually broad.
25. Ribs	Lack heads.	Double-headed
27. Skull	Bones are light. Nasals are short. Cranial cavity is large. Snout is formed of maxillae, premaxillae, vomer and mesethmoid cartilage. Tympanic bulla is ring-shaped and fused with the skull. Parietals are separate.	Bones are heavy. Nasals usually absent. Cranial cavity is narrow and elongated. Snout is formed of maxillae and premaxillae. Tympanic bulla is loosely attached with the skull. Parietals are united.
26. Scapula	Scapular spine is placed close to the anterior border.	Elongated and narrow having all the normal mammalian features.

Order 16. **Perissodactyla**

The present day horses, asses, zebras, tapirs and rhinoceroses are included in this order. The evolutionary trends of this order from Eocene to recent age is very well known.

The perissodactyls are large, herbivorous even toed mammals having a stream-lined body. The neck and facial parts are elongated. The tail with long tuft of hairs is present. The limbs are elonagted raising the body above the ground surface. Of the five digits, the 1st and 5th digits are lost. The 2nd and 4th digits remain as splints. The middle or third digit is stout and is provided with hoof. The axis of the limb passes down the third digit. This type of foot is known as *mesaxonic foot*. Horns are absent in most forms.

The stomach is undivided and simple. Intestine is long. Caecum is large and sacculated. Gall bladder is absent. The brain is highly complicated. Testes are usually abdominal. Mammae are inguinal and are with teats.

The skull is elongated. Supraoccipital bears a transverse crest. A sagittal crest runs along the sagittal suture. The paroccipital process is directed downwards and emerges from the exoccipital. The nasals are large. The orbit is surrounded by bones. The front portion of the skull and lower jaws are deep to accommodate the cheek teeth. The incisors are three in each quadrant of the jaws. Canine is present in males. Its absence in females results in the formation of a diastema. In adults molars and premolars are three in each half of the jaws. The cheek teeth are lophodont in nature. The premolars tend to be molarified. In the cheek teeth, ridges of enamel transverse to the long axis of the jaw, are present to form an efficient grinding surface. The axis vertebra is provided with a peg-like odontoid process. The dorsolumbar vertebrae are 22 or 23. The number of ribs is increased. The ilium is vertical. The upper part of both the limbs are reduced. The lower parts of the limbs are elongated. This has resulted a condition in which the elbow and the knee lie close to the body and the ankle and wrist are high up. The ulna is reduced. The magnum or distal carpal of the wrist is enlarged and united with the proximal carpals. The third metacarpal is longest. The 2nd and 4th metacarpals are vestigial. The femur is provided with a prominent process on the other surface of the shaft. The process is called *third trochanter*. The fibula is reduced. The astragalus has a doubly keeled pulley-shaped surface for articulation with tibia. The distal surface of the astragalus is flat. The third metatarsal of the hind limb is long and erect and it is known as *cannon bone*. The 2nd and 3rd metatarsals are vestigial and remain as splint bones.

Suborder (i) **Hippomorpha** The suborder hippomorpha includes extinct *Paleotheres*, *Titonotheres*, *Chalicotheres* and the horses. The first three evolved during early Eocene, attained the peak of their evolutionary development in middle Oligocene and then died out. They had a short but dramatic phylogenetic history. The horses on the other hand survived through the ages.

Family *Equidae*. The horses, Asses and Zebras are included in this family. They have only a single digit. The middle is the functional digit. The 2nd and 3rd are present as splints. Other digits are absent. The premolars in them tend to be molarified. Radius and ulna are fused.

Examples: *Equus cabalus* (Horse), *Equus hemionus* (Ass), *Equus zebra* (Zebra).

Suborder (ii) **Ceratomorpha** The suborder includes Tapir and Rhinoceros. They arose in Eocene and are surviving today. But the Rhinoceros are on the verge of extinction.

Family Tapiridae. The members of the family are less specialised. Their distribution is discontinuous as they are found in Central and South America, Malaya and Indonesia.

The Tapirs have a short proboscis formed by the nose and upper lip. The digits are stout. There are four digits in the forelimb and three digits in the hindlimb. The digits bear hoof The middle digit is large and the axis runs through it. The postorbital bar in the skull is absent The nasal bones are small and pointed upwards. The number of teeth are 42. The teeth are persistently brachyodont and without cement. Molar teeth are lophodont and without extra cusps. Example: *Tapirus* (Tapir).

Family *Rhinocerotidae*. Members belonging to this family are massive in construction and are represented by the Rhinoceros of India and Africa.

The skin is very thick and folded. Hairs are few. The horn on the nasal bone is very characteristic. The horn is made up of keratinised fibres cemented together. There is a single horn in Indian rhinos. In African rhinos, there are two horns, one anterior and one posterior along the same line on the nasal region. The limbs are massive and each ends in three digits. The digits are with hoofs. The axis of the body passes along the middle digit. The pinna is well developed. The upper lip is long and prehensile.

The skull is massive and strongly built. Canines are absent. The neural spines of the thoracic vertebra are long. More than usual number of ribs are present. The ilia are broad and vertically placed. Examples: *Rhinoceros unicornis* (Indian rhino), *Diceros bicornis* (African rhino).

Order 17. **Artiodactyla**

The members of this order are more varied than Perissodactyla. They are large herbivorous mammals. The neck is elongated. The tail is small. Members usually possess a pair of epidermal horns. Horns may be hollow or solid and are located on the frontal bone. The limbs are elongated. The number of digits are 2 or 4 in each limb. The third and fourth digits are larger and bear hoof. The axis of the body passes between the middle of the 3rd and 4th digits (*Paraxonic foot*). The eyes are large with horizontal pupil. The pinna is large. The tongue is long, mobile and prehensile. Stomach is complicated and is divided into several chambers (Fig. 9.48). Intestine is short. A short caecum is present. Gall bladder is present. Mammae are abdominal or inguinal in position and may be more than one pairs. Scent glands are often present.

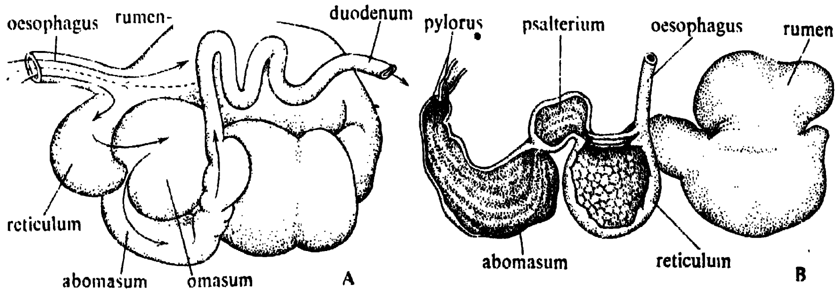

Fig. 9.48. Ruminant stomach of *Bos* (A) and *Ovis* (B).

The facial part of the skull is elongated. Odontoid process of the axis is spout-like. Thoracolumbar vertebrae are of constant number of 19 and are with long neural spines. The clavicle is absent. Ischium of the pelvic girdle is well developed. Femur has two trochanters. Radius and ulna as also the tibia and fibula are fused. Astragalus is provicded with two facets of equal size for articulation with the tarsals. Calcaneum articulates with the fibula. Both ends of calcaneum are pulley-like. Upper incisors are absent and the space left by them is hard. Premolars are simple in construction than molars. Molars are hypsodont. The cheek teeth bear longitudinal ridges of enamel.

Suborder (1) **Suina.** Some Mammalogists consider the members of this suborder as the primitive of all artiodactyles but others consider them to be distinct to occcupy a suborder status.

Members belonging to this sub-order have a heavy built body. Limbs are short. Number of digits are four and each one is hoofed. Both metacarpals and metatarsals are free. Some of the members retain the normal quota of 44 teeth. Canines appear triangular in section. Molars are bunodont with secondary cusps. Upper molars retain primitive tritubercular condition. Examples: *Sus* (Pig), *Hippopotamus*.

Suborder (*ii*) **Tylopoda.** Members of this suborder evolved from a distinct stalk during Eocene period in North America.

The limbs are long. Only the third and fourth digits are present at the end of the limbs. Hoof is absent. Nails are present at the end of the digits. Terminally the digits are provided with cushion like pad. Lips and tongue are tough. Stomach is three chambered. Red blood cells are oval in outline.

The dentition in young and adult stages differs. In young, three pairs of incisors in the upper jaw are present. But in adults, only the 3rd pair is present. The space left by the first two pairs become very hard. The lower jaw bears three pairs of incisors. Incisors are canine like. Canines are present. Premolar are reduced and their number is two in each quadrant. Molars are with 4 cusps and they are selenodont and hypsodont. In the limbs metacarpals and metatarsals are fused forming cannon bones. Lateral digits are totally lost. In the ankle navicular and cuboid remain separate. Examples: *Camelus* (Camel), *Llama*, *Alpaca*.

Suborder (*iii*) **Ruminatia.** This diverse group is most successful amongst the artiodactyles.

Body is large. Tongue is prehensile. Limbs are with two functional digits. The 2nd and 5th may remain as vestiges in some. Horns of several types are present on the frontal bones. Horns may be present in one or in both sexes. Stomach is ruminant type and is made up of four chambers (Fig. 9.46).

Incisors and at times the canines are absent in the upper jaw. Incisors and canines of the lower jaw are spatula-shaped. Premolars are reduced. Molars are hypsodont and selenodont. Connon bones are present. Fibula is reduced to a nodule-like form. Navicular and cuboid are fused together. Examples: *Axis* (cheetal), Giraffe, *Bos* (cow), *Capra* (goat), *Ovis* (sheep).

Comparison between Artiodactyla and Perissodactyla

The even-toed ungulates are included under the order Artiodactyla and the odd-toed ungulates comprise the order Perissodactyla. Both these orders show general structural similarities which are due to their remote common origin. Besides the resemblances, they show many differences which are tabulated in Table Chordata –21. The similarities and differences existing between these two orders are resulted out of similar ways of life on slightly different environments.

TABLE –CHORDATA 21

POINTS	ARTIODACTYLA	PERISSODACTYLA
1. Horns	Usually present. May be hollow or solid, located on frontal bone.	Mostly absent.
2. Digits	Third and fourth digits are larger and bear hoofs. The axis of the limb passes between the Nos. 3 and 4 digits (*Paraxonic condition*).	Only the third digit is stout and hoofed. The axis of the limb passes down the third digit (*Mesaxonic condition*).
3. Femur	Third trochanter is absent.	Third trochanter is present.
4. Talus	Has a flat surface.	Pulley-like.
5. Fibula	Usually articulates with the calcaneum.	Does not articulate with the calcaneum.
6. Nasals	Not expanded posteriorly.	Expanded posteriorly.
7. Alisphenoid canal	Absent.	Present.
8. Dorsolumbar vertebrae.	19	More than 22.
9. Odontoid process	Spout-like.	Peg-like.
10. Incisors	General tendency of suppression of upper incisors.	Present and used for cropping.
11. Canines	May form tusks.	May be reduced or absent.
12. Premolars	Not molarised.	Resemble the molars.
13. First milk molar	Not replaced.	Replaced.
14. Molars	Hyposodont.	Bunodont and low crowned.
15. Stomach	Complicated by forming different chambers.	Simple.

POINTS	ARTIODACTYLA	PERISSODACTYLA
16. Intestine	Short.	Long.
17. Caecum	Small.	Large and sacculated.
18. Gall bladder	Present.	Absent.
19. Mammae	Inguinal or abdominal.	Inguinal.
20. Placenta	Diffused or cotyledonary	Diffused.

GENERAL NOTES ON MAMMALS

Mammals occupy the highest position in the ladder of evolution. The structural diversities amongst the different groups of mammals are profound. They vary in size from that of field mouse barely six inches in length to that of a whale attaining a length of more than one hundred feet. A shrew, *Sorex minutus* (order Insectivora) is the smallest living mammal weighing about 3 grammes in comparison to whale, the *Balaenoptera* which is the largest mammalian form of about 120 tons in weight. Elephants are largest among the land mammals. The Giraffe is the longest for its elongated neck.

Mammals have colonised all environments in course of their evolution. Adaptive radiation at its zeneith is encountered amongst the mammals. It is difficult to pin point all these structural and adaptive diversities within the limited campus of a chapter of this book. In the following pages an attempt has been made to focus the attention of the students on some of the worth-noting peculiarities of mammals.

LOCOMOTION

A great variety of means of locomotion is observed amongst the mammals. They can be categorised in the following way.

Terrestrial locomotion.

The method, most frequently practised by the great majority of land mammals, is four-footed or *quadrupedal* locomotion. The mechanics of locomotion can be translated in the following way.

Walk. In walk, the animal raises the two diagonally opposite feet, for example the anterior left and posterior right, it advances them while the other diagonal pair supports and propels the body. The animal then replaces on the ground the feet it has forwarded and raises the other two. This diagonal gait is exhibited by the members of the cat family and dog family.

Pacing. In pacing the legs of the same side are moved simultaneously. Thus when the two feet on the right side are on the ground the other two on the left side are raised, and just when the latter are put down the others are raised. Giraffe, Brown bear and Camel exhibit such pacing.

Gallop. It is nothing but succession of leaps. The animal throws itself by means of the hind legs, extends its body in the air and lands on the fore feet. Example: *Stoat.*

Leaping. In certain mammals a very peculiar progression by leaps is observed in which the tail plays an important role. Australian Kangaroos progress in this fashion. When it walks slowly, it supports its body partly on its fore legs and partly on its tail and then raises the hind legs together, then in a second movement, it is supported on its hind feet, while its fore feet and tail are raised. When the animal accelerates its gait, it employs its hind legs and during the leap, the tail acts as counter balance and is held horizontal.

Bipedal. Man alone is bipedal and walks with the help of the two hindlimbs. Chimpanzees and gorillas are partially bipedal. They cannot stand upright and while walking they generally touch the ground with their digits of the forelimbs.

Arboreal locomotion.

Many mammals spend their entire lives on trees, descending to the ground rarely or accidentally. This is true for certain monkeys and apes and as well as for many rodents and marsupials. The techniques of arboreal locomotion is most probably derived directly from the techniques of walking.

Climbing. In mounting a tree trunk alternate grasping with the hand and foot of one or the other diagonal is practised by some monkeys, and three toed anteater, *Tamandua*. Some animals climb by alternate movement of the limbs of one side and then of the other. Others climb by successive holds first by the forelimbs and then by the hind ones. Possession of a prehensile tail facilitates arboreal locomotion. In leaping from one branch to another, spider monkeys use hands, arms and tail. Some flying squirrels possess scales beneath the tail and the scales act as antiskids.

Brachiation. The special mode of progression of gibbons and spider monkeys has been termed Brachiation. It corresponds in a way to the bipedal walk but here the front limbs are used. The mechanism of the two handed locomotion is simple. First one of the hands grasps a branch and draws the body forward. Then the body oscillates on that pivot made by the hand and the other hand extends to hold another branch. If the animal wants to go from one branch to another little far off branch a short glide occurs between the holds.

Aquatic locomotion

Swimming. Aquatic mammals swim in water with the aid of modified fore or hindlimbs and with the undulation of tail. Many terrestrial animals can swim.

INTEGUMENTARY SYSTEM

The integument or skin forms the outer covering of the body. The skin together with its derivatives form an important organ system.

Skin. The skin in mammals as well as in all vertebrates is continuous with the mucous membrane of mouth, rectum, urinogenital organs, nostrils and eyelids. The skin is made up of two distinct and embryologically different layers. The outer layer is *epidermis* and it is ectodermal in origin and the inner layer is *dermis* which is mesodermal in origin. The two layers are separated by a basement membrane.

The outer layer or the epidermis is again divided into a number of distinct strata. The innermost layer of the epidermis is called *stratum germinativum* or *Malpighian layer*. This layer is made up of tall and columnar cells arranged perpendicular to the dermis. The cells divide mitotically and continually. The new cells thus formed tend always to reach the surface and on their sojourn become flattened and loose stainability. The layer formed by these flat cells is known as *transitional layer*. The outermost layer of the epidermis is called *stratum corneum* or *horny layer*. The cells of this layer are flat and dead. The chief constituent of these cells are *keratin* which is a very hard, tough and insoluble protein.

The epidermis in certain parts of the body of man is a bit different. In the thick skin on the soles of the feet and palms of the hands the transition from Malpighian layer to corneal layer is not so abrupt. The transitional layer in these parts of the body is further subdivided into an inner *stratum granulosum* and an outer *stratum lucidum*.

The thickness of the epidermal part of the skin remains fairly constant because the rate of proliferation of the stratum germinativum is nearly equal to the loss of corneal cells.

The dermis or *corium* is thicker than the epidermis and is made up of connective tissue fibre, smooth muscle fibres, blood vessels, nerves and glands. In whales and seals the fat forms a thick layer called *blubber* which acts as food reservoir and also helps in maintaining body temperature.

The pigments of the skin or *melanin* in mammals never remain confined in specialised cells but they remain in the cells of the deepest layer of the epidermis.

Integumentary derivatives

Glands. A large variety of epidermal glands are present in the skin of mammals. These glands are tubular or alveolar in nature and are always multicellular. The principle glands are:

Sudorific or sweat glands. These are long and coiled tubular glands. The lower part of the gland lies embedded in the dermis and the upper part is constituted by a duct which opens to the outside through a pore. The distribution of sweat glands in different mammals is not uniform. In case of man the sweat glands are more numerous on palm, sole and arm pits. In cat, dog and rat sweat glands are found in the sole of the feet. In rabbits the glands are found around the lips. The ruminants have sweat glands located on the muzzle and on the interdigital fold of skin. In hippopotamus the pinna houses the sweat glands. Sweat glands are absent in Tachyglossus, Cetacea and Sirenia.

The secretion of the sweat glands is known as sweat. Sweat aids in removing nitrogenous wastes and helps in the regulation of body temperature. The sweat is watery in appearance but its colour is red in certain mammals like hippopotamus and Macropus. It is believed that the *gland of Moll* in the eye margin of man is modified sweat gland and similar is the case with *Ceruminous* or wax secreting glands in the external ear passage.

Sebaceous glands. These glands are alveolar in nature and are generally associated with the hair. But they also occur in hairless parts of the body, i.e. around the genital organ, tip of the nose and border of lips independently. These glands are absent in Pangolin, Cetacea and Sirenia. The secretion of the gland is known as *sebum*. It is oily in nature and it helps in keeping the body oily. *Meibomian glands* in the eyelids are modified sebaceous glands. *Scent glands* too are modified sebaceous glands. The secretion of scent glands are sex attractants. In the deer family scent glands are located near the eye. In carnivores scent glands are found near the anus and pigs and goats have scent glands in between their toes.

Mammary glands. The mammary or milk producing glands are found in all mammals. The mammary glands are built on the same general plan though variations occur. Each gland is made up of a number of *lobules*. Each lobule consists of a number of *alveoli* which contain the secretory cells. The small ducts emerging from the alveoli gradually converge to form a large duct. Many such large ducts unite and form a common duct which opens to the outside through the *nipple*. The ducts and alveoli remain surrounded by abundant adipose tissue and contributes to the size of the mammae or breast of the females. The secretion of the mammary gland is milk. Mammary glands are active only at certain times—immediately after the young is born and generally as long as active sucking by the young continues. The development and functioning of the mammary glands are controlled by hormones secreted by the ovaries, anterior lobe of pituitary and adrenal cortex.

Mammary glands are compound tubular type in Prototheria and they lack nipples and as a result the glands open directly on the body surface. In Prototheria mammary area are depressed. In Metatheria and Eutheria nipples are always present.

Mammary glands are distributed along a *milk line* which appears on either side of the body extending from the base of the pectoral limb bud and pelvic limb bud during early embryonic development. There may be a single pair of mammary glands as in man and there may be as many as eleven pairs of mammary glands as in certain insectivores. The distribution of mammary glands is related to the habit of the mother when nursing her young and thus may be axillary, thoracic, abdominal or inguinal in position.

Hair. Hair is a mammalian monopoly. During embryonic development in all mammals the body becomes covered with a coating of fine hair called *Lanugo*. Lanugo hairs are absent on the ventral surfaces of hand and feet. The lanugo hairs are transient and are shed sometimes before birth. The second set of hair then appear. In most mammals the entire integument remains covered with hairs, but in some the hairy coat is secondarily lost and only traces remain. Thus in some adult and large whales a few coarse hair is present near the snout. Such a condition is known as *Hypotrichosis*. Failure of hairs to develop lead to *Atrichosis* condition. Occasionally such human beings are found. Presence of excess of hair is called *Hypertrichosis*.

Hair is entirely epidermal in origin. During development a small thickening in the epidermis pushes down into the dermis. The depression become cup-shaped and the dermis rushes into this cup-shaped depression to make up the *hair papilla*. The blood vessels which enter into the papilla bring nourishment to the cells of the stratum germinativum. As this process is going on, the epidermal ingrowth splits leaving a *central shaft* and a space called *follicle* in which the hair lies. The cells of the follicle bud off one or more masses of epidermal cells which later on develops into sebaceous glands. Within the follicle the hair shaft become surrounded by two layers of cells which do not go out beyond the limit of the follicle. The inner layer is called *Huxley's layer* and the outer layer is called *Henle's layer*. The hair shaft is entirely cellular and in cross-section shows three distinct regions—a central core or *medulla,* middle *cortex* and outer *cuticle.* At the base of the follicle the hair forms a bulb like enlargement called *root.* Growth takes place at the root. Beyond this point the cells gradually die and the shaft or the projecting part thus become made up of dead and cornified cells.

The growth of hair may be *definitive* or *Angora.* Angora hairs grow to a considerable length and then they are shed. The head hairs of man are of angora type. Definitive hairs, on the other hand, grow to a certain length and then stop growing. They are then shed but replaced very quickly. Eye brows, eye lashes and body hairs are definitive type. Angora hairs may persist for several years but definitive hairs last for only a few months.

Hairs in different parts of the body show some variation in the direction in which they grow or slant. Hairs grow in different patterns or *hair currents.* When hair currents diverge *parts* occur and when they converge *crests* or *tufts* occur. Spiral arrangement of hairs results *whorls* or *vortices.* The cowlick on the forehead of human being is an example of whorl. In most mammals the hair parts on the mid-dorsal line and slopes towards the ventral side, but the condition is reverse in sloths for their habit of hanging upside down.

The colour of the hair is due to the presence of pigments in the intercellular spaces of the cortex. The nature and amount of pigments present determine the shade. Predominant pigment is normally brown. But black and red pigments may also be present. Absence of both or one or different combination or dilutions of the two bring about the variations of shade. Lack of pigments and presence of air spaces between the cells of the medulla imparts white colour to the hair.

Density of hair is variable in different mammals. Those living in cold climates of North and South or at high altitudes possess thick hair coat. Tropical mammals have sparse hairs. The quality of a *fur* is determined by the degree of development of the under fur. The under fur consists of large number of short and densely arranged hairs interspersed between large and coarse hairs.

The type of hair in different parts of the body of the same individual varies. Mane of horses and lions are special type of hairs. Vibrassae on the snout of many mammal are special and sensitive hairs. In spiny ant eater (Tachyglossus), hedge hog and porcupine the hairs in part have become modified into spines or quills to act as organs of defence.

Claws, Nails and Hoofs. The distal end of the digits in mammals are provided with either claws or nails or hoofs (Fig. 9.49). They are derived from the horny layer of the epidermis. The single fact that makes these structures different from all other epidermal structure is that they always grow parallel to the surface of the skin. Nails, hoofs and claws are built on the same architectural plan.

CLAW. A claw is composed of a scale like plate which takes the dorsal position. The plate is called *unguis.* Another plate called *subunguis* lie beneath or ventral to the unguis. The unguis is better developed of the two. The claw covers the terminal bony phalanx to strengthen it. In mammalian claws the subunguis is reduced in size and is almost continuous with the *torus* or *pad* at the end of the digit. The claws in the members of the cat family are retractile and the claws when not in use are withdrawn into a sheath. In lemurs the second digit on each hindlimb is provided with claw while the other digits are provided with nails. In tarsier the second and third digits of the hind foot are clawed, the others are with nails.

NAIL. In nails the unguis is better developed. The unguis is broad and flat. The

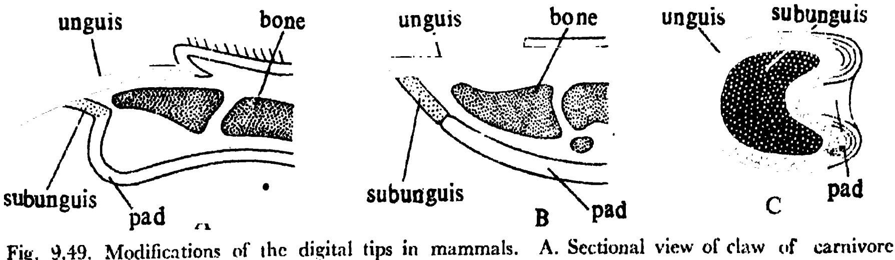

Fig. 9.49. Modifications of the digital tips in mammals. A. Sectional view of claw of carnivore. B. Sectional view of hoof of horse. C. Front view of the hoof of horse.

subunguis is much reduced and its ramnant is present under the tip of the nail. The 'root' of the nail or the region from where the growth of the unguis takes place lie embedded in a pocket under the skin. The pocket is called *nail groove* or *Sulcus unguis*. Beneath the nail and its root lies the *nail bed*. The nail bed is made up of three distinct regions proximal, middle and distal. The proximal part is known as *matrix* and it is concerned with the development of the nail. The matrix in man may be seen through the base of the thumb nail as a crescent-shaped area called *lunula*.

HOOF. Hoofs are characteristics of ungulates. In hoofs the unguis is most well developed and curves all the way round the digital end enclosing the subunguis. The torus or pad lies just behind the hoof. The torus is known in case of hoofed mammals as *Frog*. The unguis is of harder consistency than the subunguis.

Horns. Excepting their presence in a few living lizards and in extinct dinosaurs the horns again are mammalian monopoly though they are found only in certain members of the order Artiodactyla and in rhinoceros of the order Perissodactyla. According to structure and mode of formation four types of horns are recognised (Fig. 9.50).

Keratin-fibre horn. Keratin-fibre horn is found only in the rhinoceros. It is a hard conical structure located on the *fronto-nasal* region of the skull. It is composed of a cluster of long fibres cemented together by a mass of hard and keratinised cells growing from the epidermis. Each fibre resembles a very thick hair and emerges from a *dermal papilla*. The fibres are not true hairs since their bases lack follicles. In Indian rhinoceros there is a single horn. In African rhinoceros there are two horns. The two horns are located on the same median line along the fronto-nasal bone and the larger one lies in front.

Hollow horns. Cattle, sheep, goats and buffaloes possess hollow horns. In certain species they are present only in males but in most both the males and females possess horns. There is a pair of horns one each on the *frontal* bone The horn consists of a bony projection from the frontal bone of the skull. The projection is covered over by a cornified layer of epidermis. A cavity extends into the bony projection. The horny layer is never shed.

In very young animals the first indication of the future development of horn is seen in the formation of the *os cornu*. os cornu is a loose button-like mass of bone cells which can be felt under the skin on the frontal bone. The os cornu later on becomes fused with the frontal bone. If the os cornu is destroyed the horn fails to develop.

Prong horns. This is an unique type of

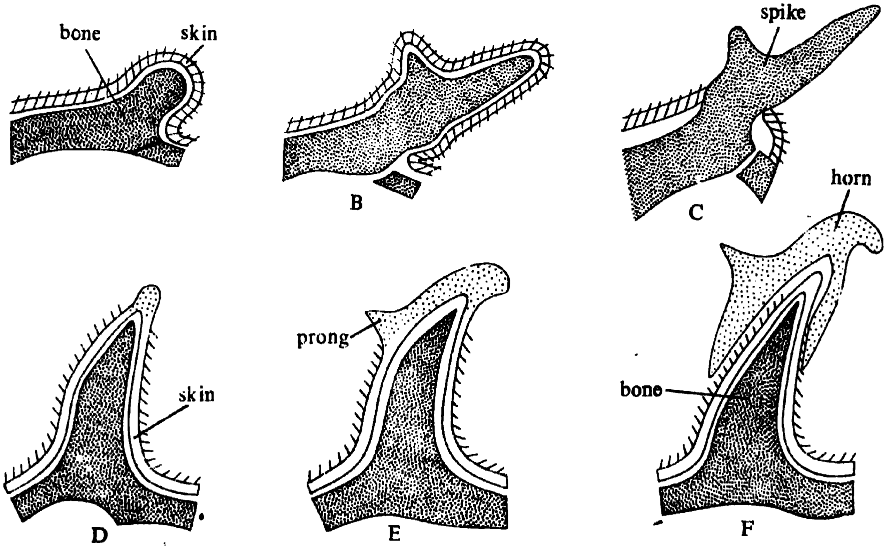

Fig. 9.50. Antlers and horns of mammals. A–C. Stages of formation of antler. D–F. Stages of formation of prong horn.

horn found only in the antelope, *Antelocapra americana* of the Western America. It consists of a conical projection on the frontal bone. A horny epidermal sheath covers the projection. The sheath usually bears one side projection or *Prong* (Fig 9.50 D–F), but as many as three have been encountered. The epidermal sheath is shed with annual periodicity and a new epidermal sheath again covers the bony projection.

Antlers. Antlers are present only in the male members of the deer family. In reindeer and caribou both the sexes bear antlers. When fully developed the antler is nothing but a solid bone and as such entirely mesodermal in origin. Though it is better to consider the antlers as parts of the dermal skeleton, it is discussed under the integumentary derivatives simply because the antler is formed under the influence of the integument.

During the early phase of the growth of the antler an out growth on the frontal bone appears one on each side. It remains covered with soft skin (Fig. 9.50A). The blood vessels on the overlying dermis bring minerals and other elements necessary for the growth of the structure. At this stage the antler is said to be "in velvet". As autumn approaches, a wreath like burr grows round the base of the antler. This burr cuts off blood supply to the skin and on the antler and as a result the skin dries, cracks and is ultimately rubbed off by the deer. At the end of the first season the antler appears as a single 'spike' (Fig. 9.50C). A young buck with a single spike on each side is called a 'spike buck'. In the spring certain degenerative changes occur between the burr and the frontal bone and as a result the antler becomes loose and finally is shed. The skin closes the area. Soon a new antler begins to develop but this time it is branched. The developing antler remain in velvet until autumn approaches. Then it comes up in the same fashion as described and is again shed in the following spring. Each time new branches appear making the structure very complicated.

Antler growth is regulated by the secretions of both testes and anterior lobe of the pituitary. If castration is made before eight months of age antlers never grow. If castration is made at a stage when the antlers are in velvet, antlers do not develop and remain permanently in velvet. Castration of deer with fully grown antler results in its prompt shedding. Subsequently new antler is formed but they remain permanently in velvet. Antler growth can be induced in female deer by the administration of the male hormone—*Testosterone.*

In giraffe both sexes possess small and inconspicuous antlers. But they remain permanently in velvet.

Epidermal scales. Many mammals possess epidermal scales. Excepting the scaly ant-eaters and armadillos the scales, when present remain confined in tail and paws. Since the scales and hairs in mammals are found in close association with each other it is believed that hairs have been derived from scales.

In ant eaters the body, excepting on the ventral surface, is covered with large, overlapping and horny scales. The scales are typically reptilian in nature. But ecdysis occurs singly. In armadillos the scales are large and the scales fuse to form plates over the head, shoulders and hind parts. Ecdysis in true sense is absent but a process of wearing away of the scales from the surface and replacement from beneath is present.

Epidermal scales are present on the tails of rats, mouse, beaver and muskrat. These scales are arranged in an imbricated fashion though the degree of cornification is not very pronounced and there is no ecdysis.

In most mammals the under surface of the hands and feet bear evidences of former presence of scales. The *friction ridges* according to some represent such rudimentary scales. On the under surface of the foot of rat there are distinct and elevated pads called *Tori*. Friction ridges are located on these tori. There are eleven such tori in the foot of rat. Of these five are *digital tori* located at the tip of the digits, four are *interdigital* being placed between the spaces intermediate between the digits, one is *thenar* at the base of the first digit and one is *hypothenar* at the base of the fifth digit.

ENDOSKELETAL SYSTEM

Skull. Variation in the structure of skull is present amongst the different members of the class. But all the members share certain features in common. In the general plan of the laying of skull bones, the shadow of a reptilian ancestry is clearly indicated.

The most noteworthy feature of the mammalian skull is the increased capacity of the cranium. The cranium is expanded dorsally and laterally to house the much developed brain. The other feature of mammalian skull is that excepting the mandibles, hyoid and auditory ossicle all component bones are firmly united and their line of union form *suture*. The articulation of the upper jaw and mandible is at the *glenoid* or *mandibular fossa* of the squamous region of the temporal rather than at the quadrate. This type of articulation is known as *craniostylic* or *amphicraniostylic* type of jaw suspension.

A reduction in the number of skull bones has appeared in mammals. The reduction is due mainly to *loss* of certain bones and *fusion* of others. The number of bones in the skull is about 35. Bones of the ancestors that have disappeared are *prefrontals*, *postfrontals* and *postorbitals*. Bones that have become reduced are the *quadrate* of the upper jaw, *articular* of the lower jaw and the *hyomandibular*. The quadrate has formed the *incus*, the articular has formed the *malleus* and hyomandibular has formed the *stapes*. Incus, malleus and stapes constitute the *ear ossicles*. Cases of fusion is encountered in the temporal region. Another common area of fusion is found in the cartilage bones of the sphenoid complex. The basal portion of the *frontal* often unites with the *orbitosphenoid* to form the *presphenoid* bone. The basisphenoid and alisphenoid may also fuse. *Pleurosphenoid* bone is absent in mammals. Epipterygoides derived from paletopterygoquadrate bar occupies its place. These are then known as alisphenoid. The four separate bones of the occipital region are fused in some mammals forming a single occipital bone. Otic bones are fused to form the *petrosal* enclosing the internal ear. The petrosal may fuse with squamosal and tympanic forming the *petrosus region* of the temporal bone.

Mammals lack a supratemporal arcade. But the infratemporal arcade or zygomatic arch is present. As a result, mammals possess a single temporal fossa. An anteriorly projecting process from the squamosal and a posteriorly projecting process from the jugal unite to form the zygomatic arch. The orbit is formed by lacrimal, maxillary, orbitosphenoid, palatines and sometimes ethmoid. The orbital and temporal fossa are often confluent but in many cases they remain separated by a bar formed by a downwardly projecting postorbital process of the frontal joining a dorsal projection of the jugal.

The nasal cavities of mammals are large. The nasal cavities are surrounded by premaxillaries, maxillaries and nasals. Mesethmoid is a vertical cartilaginous plate separating the right and left nasal cavities. A cribriform plate separates the nasal cavity from the cranial cavity.

A hard and bony secondary palate is found in mammals. Premaxillary, maxillary and palatine bones participate to form it. In whales and edentates pterygoid forms a part of the palate. Pterygoid is reduced in other mammals.

The lower jaw or mandible articulates with the squamosal. It is made up of a single piece called *dentary*. The articulating surface of the mandible is the *condyle*. A coronoid process from the posterior portion of the mandible extends into the temporal fossa. An angular process at the posterior ventral angle of the mandible is prominent in many mammals. The two halves are united in front by a symphysis.

A typical mammalian hyoid apparatus consists of a body or *basihyal* and two pairs of *cornua* or *horns*. The anterior cornua are called *styloid processes* and are attached to the otic region of the skull. In some forms a chain of bones between otic region and basihyal are found. These bones are known respectively as *tympanohyal*, *stylohyal*, *epihyal* and *ceratohyal*. The posterior cornu is often small and called *thyrohyal* which is connected to the *thyroid cartilage* of the larynx.

Vertebral column. The vertebrae are *amphiplatian* or *acoelous*. The centra are formed from pleurocentra and the hypocentra form intervertebral disc. The centra of mammalian vertebrae excepting monotremes and sirenia bear epiphysis at either end during early phase of development. But in adult forms, these becomes fused with the centrum.

The mammalian vertebral column is divided into five distinct regions. They are *cervical*, *thoracic*, *lumbar*, *sacral* and *caudal*. Number of cervical vertebrae are 7 and is a constant feature in most mammals. The length of neck is determined by the length of individual vertebra rather than by an increase in number. However, the number of cervical vertebrae are 6 in two toed, sloth *choloepus*, 9 in three toed sloth *bradypus*. In the sirenian manatee *Trichechus* there are 6 cervical vertebrae. Fusion of some or all cervical vertebrae are seen in whales, marsupial mole, Jerboas, etc. The first cervical vertebra is called atlas. The atlas is provided with a pair of concavities for articulation with the occipital condyles of the skull. The second cervical vertebra is called axis. It is provided with a peg like odontoid process. Cervical ribs are absent excepting monotremata. The presence of *foramen transversarium* or vertebroarterial canal for the passage of artery, vein and a sympathetic nerve plexus in the cervical vertebrae is very characteristic of mammals. The seventh and sometimes the sixth vertebra may lack this foramina. In perissodactyle the cervical vertebrae are *opisthocoelous*.

The number of thoracic vertebrae are variable. The minimum number is 9 as in *Hyperoodon*. The greatest number is 25 as in sloths. Fusion of thoracic vertebrae in living mammals is not known. Thoracic ribs are present in the thoracic vertebrae. These ribs connect the vertebrae directly or indirectly with the sternum. Articular facets that are found in the thoracic vertebrae are *tubercular facets* and *costal demi-facets*.

The lumbar vertebrae are large and strongly buil: Usually there are 4 to 7 lumber vertebrae. In the whale *Neobalaena* the number is 2 while in dolphin the number is 21 24. The transverse processes of the lumbar vertebrae are directed forward. Some of the anterior lumbar vertebrae are provided with *Mammillary processes* or Metapophysis. The metapophyses of the armadillos are large and blunt and help to support the carapace.

The sacrum consists of several vertebrae firmly ankylosed together and serves for articulation of pelvic girdle. The number of separate elements that fuse is variable. There are five such elements in man and horse, 3 in dog and cat and 4 in pig. Extra elements coming from lumbar or caudal regions are often incorporated. The vertebrae are pierced by sacral foramina both on the dorsal and ventral sides. The first sacral vertebra is provided with *lateral masses* which bear cartilage covered *auricular surfaces* into which the ilium fits in.

The number of caudal vertebrae is extremely variable. In man there are 3 or 4 caudal vertebrae fused to form the *coccyx* and in *manis* there are 50 caudal vertebrae. The anterior caudal vertebrae bear neural arch, spine, zygapophysis, etc. But these structures gradually diminish in size towards the tail end and thus the caudal vertebrae at the posterior end are represented by centra alone. Chevron bones are found in whales and edentates.

Sternum. The sternum of mammals is composed of a series of separate bones arranged in linear order. Three distinct regions are recognised in the sternum. They are anteriorly placed *presternum* or *manubrium*, a middle *mesosternum* consisting of several sternibrae and a posterior *metasternum* or *xiphisternum* from which hangs the *xiphoid cartilage*. The prosternum is keeled in bats. The sternal elements are fused in cetacea, sirenea and primates. In man the entire structure is flat and is made up of three parts - an anterior manubrium, middle body and posterior xiphoid process. The clavicle and first pair of ribs join the manubrium. The second pair of ribs joins the sternum at the point of junctions between manubrium and body. Five more pairs of ribs join the body of the sternum in an even manner. No rib reaches the xiphoid process.

Ribs. Mammalian ribs are made up of two distinct regions -an upper and bony *vertebral region* and 'a lower *cartilaginous region*. The lower region joins the sternum directly or indirectly and is called costal cartilage. The ribs of monotremes are with three regions. Uncinate process is absent in mammalian ribs. Mammalian ribs are usually bicipital. The part of the rib between the two heads is called ***neck***. The two heads are called ***capitulum*** and ***tuberculum***. The remainder is called ***shaft***. The area where the shaft is very much curved is called the angle of the shaft. The ribs which are directly in contact with the sternum are called *True ribs*. *False ribs* are the posteriorly located ribs. The costal cartilages of such ribs are either united with the costal cartilage of the last true rib or float freely. False ribs which terminate freely are called *floating ribs*.

The thoracic ribs are well developed in mammals. The tubercular head of the rib articulates with the tubercular facet located on the ventral side of the transverse process and the capitulum articulates with the demifacet located in between two adjacent vertebrae.

The number of mammalian ribs are

variable. There are 9 pairs of ribs in whales and 25 pairs in sloth. Number of true ribs ranges from 3–10 pairs.

Girdles and limb bones

Pectoral girdle. In monotremes each half of the pectoral girdle consists of *scapula*, *coracoid* and *precoracoid*. The coracoids establish a connection with the manubrium of the sternum on the ventral side. Precoracoids join with the episternum which lies anterior to sternum. The coracoids take major share in the formation of the glenoid fossa. Clavicles and interclavicles are present. In higher forms the precoracoid and interclavicles are lost. The coracoid becomes reduced to a coracoid process which lie on the scapula adjacent to glenoid fossa. Scapula is provided with scapular spines in most cases and the spine ends in acromian process. In some mammals the clavicle persists as a strong arch. In others it is lost. Presence of strong clavicle is correlated with the freedom of movement of the fore limb.

Forelimb bones. The humerus bear near its distal end a *supracondylar foramen* in most mammals. The brachial artery and median nerve of the arm passes through the foramen. Brachial vein does not pass through it. Radius and ulna are connected with the distal end of the humerus by a hinge joint which allows movement in one plane. In primates the radius and ulna are not arranged in a fixed position, but are articulated in such a way that the distal end of the radius can rotate about the ulna. The ulna articulates with the humerus through the olecranon fossa of the humerus by a notch. The proximal end of the ulna is called olecranon process or elbow.

Carpal bones are many with a tendency towards fusion. Metacarpals are long. Number of phalanges in the first digit is 2 while in the rest the number is 3. In horse only the 3rd or middle digit persists. This digit bear hoof. 2nd and 4th digit may remain as *splints*. In cattle the 3rd and 4th digits are functional. Each consists of three phalanges. The terminal phalanx bear the splitted hoof. There are two metacarpals in cattle. Of these one is large and the other is small. The large one is formed by the fusion of third and fourth digits and the line of fusion can be seen. Small metacarpal is a vestige of the 5th digit.

In bats the forelimbs are modified. All the elements of the forelimb are elongated but the ulna is very much reduced. The proximal end of ulna is present and its distal end is fused with the radius. The first digit is free and bears a claw. Metacarpals and remaining digits are much elongated. The third digit is the longest.

The pentadactyle limbs of cetaceans and sirenians are webbed to form the flippers. The central digit is with more than usual number of phalanges.

Pelvic girdle Ilium, ischium and pubis are the constituent bones of the pelvic girdle. The elements unite to form a single bone—*innominate*. Both ischia and pubes form symphysis in many mammals but in others the ischia do not meet ventrally so that only pubic symphysis is present. The three bony elements in most cases are united at the acetabulum. A small acetabular (cotyloid) bone is frequently present in the acetabulum as a substitute for pubis or in some cases for ilium. A large obturator foramen bounded by pubis and ischium is characteristic of mammals. The ilium and sacrum is firmly ankylosed. The ilium in primates and specially in man is broad and flat in correlation with upright posture. Pelvic girdle and hindlimbs are absent in whales and sirenia, but remnants of paired pubis and ischium are present.

In monotremes and marsupials, from each pubis a *marsupial bone* or *epipubic bone* extends towards the ventral wall of the abdomen.

Hindlimb bones. Femur is strongly built. The head of the femur articulates with the *Acetabulum*. *Trochantars* on the femurs are usually three in number. A *patella* or *knee cap* is always present. The tibia are stronger than the fibula. The fibula is reduced in size or is fused with the tibia forming a small splint. Cnemial crest on the fibula is present. Tarsal bones are distinct entities. The proximal tarsal bones are represented by *astragalus* and *calcaneum*. The shape of the astragalus varies in different mammalian orders. The astragalus bears at its proximal end a grooved surface called *trochlea* which articulates with tibia and fibula. The neck and head of astragalus are of varying shapes. In lower mammals an astragular foramen is present at the outer border of trochlea. The heel of the foot is formed by a projection from the calcaneum. Reduction of the number of digits is more pronounced in the hindlimb than that in the forelimb.

Mammals exhibit three types of foot posture. The most primitive is the *plantigrade posture* exhibited by man, bear and some insectivores. In plantigrade animals the whole foot remains in contact with the ground during locomotion. *Digitigrade posture* is exhibited by cat, dog, etc. In this posture only the digits remain in contact with the ground and the wrist and ankle remain elevated. The *unguligrade posture* is most specialised and is exhibited by swiftly moving animals like horse, deer, etc. In this posture only the hoof remains in contact with the ground.

DIGESTIVE SYSTEM

The basic structures of the digestive system in mammals is more or less constant. Some of the parts associated with the system depict modifications. The modifications are discussed below.

Tongue. A muscular tongue is present in the floor of the buccal cavity of all mammals. The tongue shows many modifications in form but not in function. The tongue is movable in all groups of mammals excepting the whales. The tongue muscles of ant eaters extend as far as the sternum. The tongue acts as prehensile organ in most ruminants and ant eaters. In the cat family, the filiform papillae are highly cornified and are used in rasping the flesh off the bones. In dogs the tongue helps in the maintenance of body temperature because the sweat glands on the skin play little role in temperature regulation.

Teeth. Teeth are present in all mammals though a secondary tooth less condition is exhibited by some mammals. The adult platypus bear epidermal teeth but no true teeth are present. In *Echidna* teeth are absent in all stages of life. In certain ant-eaters and in adult whalebone whale teeth are lacking.

Thecodont condition is the rule in mammals. The teeth are *diphyodont*. The first set called *baby teeth*, *milk teeth*, *lacteal teeth* or *deciduous* teeth are lost and then are replaced by a second set. In bats and guinea-pigs the milk teeth are lost even before birth. *Monophyodont* condition is exhibited by platypus, toothed whales and sloths. The marsupials retain all their milk teeth excepting the last premolars.

Heterodont condition is the usual feature in mammals. Homodont condition is present in certain cetaceans. Pinnipedians shows a tendency towards homodont condition.

There are four different types of teeth. *Incisor* lie in front on either side. The incisors are followed by a single *canine*. It is large, long crowned and is with a single root. Following the canines there are the *premolars* or bicuspid teeth. These teeth are with two roots and are complex in form. Lastly comes the *molars* which are with many roots.

The number of teeth in any particular species is constant. The maximum number of teeth in heterodont condition is 44. There are mammals with teeth fewer in number than this. This is because of the fact that there has occurred reduction in the number of one or more types. This constancy of the number of teeth has become a tool in the hands of taxonomists for the purpose of classification. A *dental formula* to show the constant nature of teeth in a given species of mammal has been devised. Since two halves of the jaw correspond, only the number of teeth on one side is recorded in making the dental formula. Those of the upper and lower jaws are separated by a horizontal line so that they appear in the formula as numerator and denominator. The kind of teeth is indicated by the initial letters i, c, p, m indicating incisor, canine, premolar and molar respectively. For further simplification the initial letters are often omitted. When a certain type of tooth is absent a zero is in use to indicate the fact. Dental formula of some mammals:

$$\text{Cat}\ \frac{3.1.3.1}{3.1.2.1},\quad \text{Dog}\ \frac{3.1.4.2}{3.1.4.3},\quad \text{Mole}\ \frac{3.1.4.3}{3.1.4.3},$$

$$\text{Squirrel}\ \frac{1.0.2.3}{1.0.1.3},\qquad \text{Rat}\ \frac{1.0.0.3}{1.0.0.3},$$

$$\text{Horse}\ \frac{3.1.4.3}{3.1.4.3},\quad \text{Elephant}\ \frac{1.0.0.3}{0.0.0.3}.$$

Depending upon the feeding habit and the type of food taken the premolars and molars have undergone changes in their shape: When the cusps in the cheek teeth remain separate and rounded the tooth is called *bunodont* type. In man and in some mammals the cheek teeth are bunodont type and they are used in grinding. If the cusps are joined to form ridges or *lophs*, the tooth is called *lophodont*. The cheek teeth of elephant is lophodont type. When the cheek teeth are with sharp cutting crowns the teeth are called *secodont.* This condition is present in terrestrial carnivores. Cheek teeth with cresent-shaped cusps are known as *selenodont.* In ruminants and horses the teeth are selenodont type. A tooth with a low crown is called *brachydont* and when the crown is high is called *hypsodont.*

The origin of the complex cheek teeth of mammals was a controversial issue for a long time. The simple and single rooted incisor and canine show little modifications and are not taken into consideration in any discussion on the origin of cheek teeth. Two theories have been put forward to explain the origin of the complex cheek teeth. The first theory advocates that the cheek teeth originated by the fusion of two or more conical teeth. In dugong several *enamel organs* fuse to form the molar teeth. As the theory is not supported by embryological evidences and the condition found in dugong is considered as exception, the theory has been discarded. The other theory holds that starting with a primitive conical tooth, two additional projections or buds developed giving rise to the so called *triconodont shape* (Fig. 9.51). In the second phase these *cones* shifted so as to give rise to separate tubercles or cusps arranged in a triangle. This has been called *tritubercular position.* Still later other parts may have developed from these three original tubercles so as to form additional cusps or folds and thus arrived the varied types of mammalian cheek teeth that exist today. Since the theory is supported by considerable paleontological evidence, it is held today.

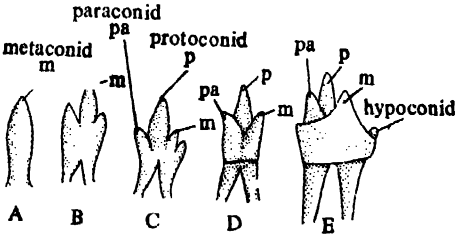

Fig. 9.51. Showing the evolution of mammalian cheek teeth from simple conical reptilian tooth. A. Reptile. B. *Dromatherium.* C. *Microconodon.* D. *Spalacotherium.* E. *Amphitherium.*

Some mammals possess unusual teeth. The tusks of elephants are modified upper incisors with open root canal. They grow continuously throughout life. The incisor teeth of rodents and lagomorphs are with open pulp cavity. They are chisel-shaped and grow continuously. The tusks of male wild boar are greatly developed canine teeth with persistent pulp cavities. Both upper and lower canines take part in the formation of tusks in male boar. Male and female walrus have tusks. These are enlarged upper canine teeth. The carnassial teeth of the carnivores is formed by a premolar above and a molar below. It is used in shearing.

Stomach. The stomach in mammals is transversely arranged and in most forms they are typical. In platypus the two limbs namely cardiac and pyloric are almost fused along the lesser curvature and appear as a wide sac. Since the lining epithelium is devoid of glands the stomach in monotremes is not considered as a *true* stomach. The cardiac and pyloric regions in some monkeys and rodents are marked by a constriction in between them. Such stomach is known as *hour-glass* stomach. The pyloric part of the stomach of kangaroo is provided with many peculiar and sacculated folds in its wall. In the blood sucking bat, *Desmodus*, the pyloric part has become elongated to form a caecum-like structure for storage of sucked blood.

Stomach of ruminating mammals is very complex. The stomach in cattle is constituted of four separate chambers. These chambers are known as *rumen* (*paunch*), *reticulum* (*honeycomb*), *omasum* (*psalterium*) and *abomasum* (*rennet*). Of these, the first three are considered by many as modified parts of the oesophagus but embryological studies show that they are really parts of stomach. The rumen is large and sac-like and serves mainly as storage organ. The cattle feed fairly rapidly and fills the rumen with grain, grass and other herbage. The food within the rumen is churned by mascular contraction and undergoes certain bacterial fermentation during its stay in the rumen. Food from the rumen passes by degrees into the reticulum or directly to the oesophagus and thence to the mouth by a process of *retroperistalsis.* Such food regurgitated into the mouth is called *cud* or *bolus.* When the cud is well masticated and thoroughly mixed with the secretion of the salivary glands, it again passes into the rumen. A new bolus is again formed and chewed and seat back to the rumen. The process is repeated several times and when all the food is well masticated it passes to the reticulum and then to the omasum and abomasum. The abomasum is provided with gastric glands.

In camels the stomach is three chambered, the omasum being absent. The rumen and reticulum parts of the stomach of camels are provided with pouch-like *water cells*. Their openings are guarded by sphincter muscles. At one time it was believed that the camels store water in their water cells and make prolonged journey without drinking water. But the view is no longer tenable. The pouches can by no means hold as much water as would be required by the animal on a prolonged journey through the desert where no water is available. Recent studies have shown that the camels get their water requirement during journey by the breaking down of the glycogen of the muscles and fat of the hump. Physiologists have shown that for each 100 gm. of fat oxidised in the body 110 gm. of water is formed. They also have shown that the water cells do contain some metabolic water. The water is pure in nature and helps in moistening the food.

The stomach of whales and hippopotamus is divided into several chambers.

The glands that are found in the stomach have been named according to their location. The glands located on the cardiac part of the stomach are called *cardiac glands*. Those located on the fundus and pyloric parts are called *fundic* and *pyloric* glands respectively. The fundic glands are of greatest importance in digestion. There are three types of fundic glands. They are *mucous neck cells*, *chief* or *zymogen cells* and *parietal* or acid secreting cells. The secretion of the stomach is known as *gastric juice*. It contains mucous, hydrochloric acid, pepsin, renin and gastric lipase. The concentration of gastric hydrochloric acid in human gastric juice varies from 0·05 to 0·3 per cent. In dog this concentration may be as high as 0·6 per cent.

Caecum. A caecum at the junction of the large and small intestine is present in most mammals. The size and the structure of the caecum varies greatly in different mammalian orders. As a general rule the caecum is larger in vegetarian than in carnivorous forms. The caecum is large in eutherian rabbits. In hyrax four distinct caeca are present. Of these the posterior pair bear *vermiform appendix*. In man, monkey, civet and few rodents the distal part of the caecum is degenerated and has formed the vermiform appendix. Caecum is simple in monotremes and absent in sloths, cetacea and a few carnivores. Marsupial koala bear the longest caecum of all. It is about 250 cm. long.

RESPIRATORY SYSTEM

The basic respiratory organs are same as in guinea-pig. In cetacea, the epiglottis and arytenoid are long forming a tube which extends into the nasal chamber. A *third bronchus* is present in some cetacea and artiodactyla which opens into the right lung in front of the ordinary bronchus. Air cavities are often associated with various parts of the respiratory tract. An Eustachian tube is present connecting the tympanic cavity to the pharynx. Air sinuses of considerable dimensions may sometimes remain present into the bones of skull especially the maxilla and frontals. These spaces are called *maxillary aorta* and *frontal sinuses*. Pharyngeal air sacs are present in howler monkey - *Alouatta*.

BLOOD VASCULAR SYSTEM

The blood of mammals is warm and blood temperature ranges between 35°C to 40°C, excepting the monotremes which are cold blooded. The mature R.B.C. are nonnucleated and circular in outline excepting the camels in which the R.B.C. are elliptical in outline.

The structure of the heart is same as described earlier. A single aortic arch situated on the left side is present in all mammals. Sometimes a single trunk arises from the arch of the aorta and gives rise to both the carotids and subclavians. Sometimes two main trunks right and left *innominate* arteries arise from the arch of the aorta—each giving rise to the carotid and subclavian of its own side. Sometimes only right innominate artery is present and it gives off right subclavian and right carotid while the left subclavian and left carotid emerge separately from the arch of the aorta. In rabbit the innominate gives origin to both the carotids and right subclavian and left subclavian comes out separately.

In the venous system, in most mammals only the right precaval persists and the left precaval aborts and its vestige gives rise to *coronary sinus*. In monotremes, marsupials, elephants, rodentia, insectivora and chiroptera both right and left precavals persist. In monotremes all the pulmonary veins open by a common trunk. In metatheria and eutheria there are four pulmonary veins. These veins either open into the heart separately or two veins of one side unite to form a single lateral trunk which opens into the heart. An abdominal vein is present in Tachyglossus.

The presence of peripheral or subperipheral anastomoses is a very peculiar feature in many mammals. This is a means for *climatic thermal adaptation* and is present in whale, sirenia, seals, amphibious rodents and sloths. With the help of this arteriovenous *retes* these creature can swiftly lose heat or ensure heat retention.

Hibernation is practised by many small mammals specially the bats and rodents. The north American ground squirrel (*citellus beecheyi*) can be induced to hibernate irrespective of season.

NERVOUS SYSTEM

The central nervous system or Brain is relatively large amongst the vertebrates. The structure of the cerebral hemispheres of the forebrain is very complex. The cerebral hemispheres are large and project forward above the olfactory lobes and posteriorly above the diencephalon and midbrain. A deep *median fissure* separates the two hemispheres dorsally. Each hemisphere is again separated into an anterior *frontal lobe* and a posterolateral *temporal lobe* by an oblique *Sylvian fissure*. The roof of the cerebral hemispheres are invested with *neopallium* formed by the upgrowth of the lateral parts of the pallium. The neopallium is beset with large number of neurons. The neuron form a layer called *cortex*. Below the cortex lies a thick layer of medullated nerve fibres forming the *medulla*. Thus neopallium is made up of outer cortex and inner medulla. The cortex bear many depressions or *sulci* and lobes or *gyri*. These are formed by infolding of the cortex to increase the surface area. The hemispheres are smooth in orninthorhyncus, somewhat convoluted in Tachyglossus. In lower marsupials no convolution is present. The cerebral hemispheres of two sides are connected with each other along the middle line by a band of nerve tissue called *corpus callosum*—a structure unknown in other vertebrates and even it is absent in monotremes and marsupials. The floor of the hemispheres is thick and forms anteriorly the *corpora striata* and posterolaterally the *hippocampus*. An *anterior commissure* joins the two corpora striata and the two hippocampi are joined by a *hippocampal commissure*. A delicate membrane called *lamina terminates* runs between the anterior commissure and optic chiasma. The lateral ventricles within the hemispheres are complex. Each ventricle consists of a middle body from which three prolongations or cornu run forward, backward and outward. The *olfactory lobes* are small and lie below and in front of the hemispheres. Each olfactory lobe run backward into a olfactory tract. Each tract terminates in a round elevation called *tuberculum olfactorium*. The olfactory tracts are kept separated from the hemispheres by *rhinal fissure*. The *rhinocoel* or olfactory ventricle is ill-developed.

The diencephalon is small and is almost covered dorsally by the cerebral hemispheres. Internally the third ventricle or *diocoel* is laterally compressed. The roof is delicate and vascular. It is called *velum interpositum*. It is continuous with the *anterior choroid plexus*. Above the choroid plexus lies the ill-developed and stalked pineal body or *epiphysis*. The side walls of the diencephalon or *thalami* are thick mass of white and gray matter. The two thalami are connected together by a *habenular commissure* which lie close to the pineal stalk. The floor of the diencephalon is called *hypothalamus*. The hypothalamus bears on the ventral side the *optic chiasma* and the *infundibulum*. The peculiarity of the mammalian optic chiasma is that all the fibres of the optic nerve do not participate in forming it, but only the inner fibres decussate or cross. The *pituitary gland* is attached with the infundibular tip. Behind the infundibulum lies a round *corpus albicans* or *corpus mammillare*.

The midbrain bears on its dorsal side two pairs of optic lobes called *corpora quadrigemina* which is characteristic of mammals. The anterior pairs of optic lobes are connected with each other by a delicate *posterior commissure*. The floor of the midbrain is thick forming the *crura cerebri*.

The cerebellum is large and complex and is divided into a number of lobes. There is a large central lobe called *vermis*, two lateral lobes and two outer or *floccular lobes*. The cerebellar surface is convoluted by the formation of *sulci* and *gyri*. On the ventral side a thick band of nerve fibre called *pons Varolii* joins the cerebellar cortex of two sides. A large number of tracts of nerve fibres or *peduncles* join the cerebellum to the other parts of the brain. The medulla oblongata is thick.

SENSE ORGANS

They have the same general plan of structure as encountered in Birds and Reptiles.

Smell. Organ of Jacobson is well developed in lower groups of mammals. The olfactory mucosa has become elaborate in higher mammals because of the convolutions of the *ethmoturbinal* bones. The nasal chamber has lost its sensory functions in the toothed whales where the olfactory nerves are almost vestigial.

Sight. The structure of the eye resembles that of other vertebrates. The pecten of birds and reptiles is absent. The *sclera* is composed of condensed fibrous tissue. Most of the mammals are provided with three eyelids in each eye. The upper and lower eyelids are opaque and are provided with hair. The third eyelid is transparent and hair less. In higher forms the third eyelid is vestigial. Its vestige can be seen as a pink fold in the inner canthus of each eye. The eye-ball and the eyelids are kept moistened by the secretion of a *lachrymal*, a *harderian* and a series of *meibomian* glands for each eye. Following are the accounts of eye and its associated structures in mam-

The eyes are ill-developed and almost functionless in burrowing insectivores, moles and marsupial *notoryctes*. The eyes of whales are small. In *platanista* it is vestigial. The eyes of the whales are variously modified. In them the cornea is flat and the lens is round. The sclera is thick and the eyelids are provided with specialised lid muscles for protection against pressure.

Cartilage is absent in the sclera. A *tapetum lucidum* is present in many nocturnal form. Tapetum lucidum is a layer of light reflecting crystals located on the choroid coat adjacent to the retina. Hoofed mammals possess a *tapetum fibrosum*. In it the portion of the choroid coat is made up of a tendinous type of connective tissue which glistens in a manner similar to a fresh tendon. Carnivores, seals and lower primates possess another type of tapetum called *tapetum cellulosum*. It is composed of several layers of cells filled with small crystals of unknown organic material. The pupil is round in most forms. A vertical slit is characteristic of the cat family. The vertical slit in them become round at night. The slit is transversely arranged in many ungulates and whales. The portion of the iris bordering the pupil is modified to form an irregular, pigmented and fringe-like *umbraculum* in gazelle and camel. This is a device to protect the eye from excessive glare.

The retina of the eye bear rods and cones. But in lower orders like edentata, chiroptera and certain shrews the cones are absent. It has been shown that rods detect the differences in the intensity of light and hence the nocturnal animals usually have rods only. Rods contain a purple pigment called *Rhodopsin* which is destroyed by light but are instantly manufactured by vitamin A. The cones of the eye are sensitive to bright light and to various colours. Recently three more pigments have been detected in the human eye. They are red sensitive *erythrolabe*, green sensitive *chlorolabe* and blue sensitive *cyanolabe*. The capacity for colour vision however, is restricted amongst the primates only.

Hearing and balance. Amongst the vertebrates the ear is best developed in mammals. The accessory parts and the membranous labyrinth have become very complex in mammals.

All mammals excepting monotremata, cetacea and sirenia possess large *external pinna*. This is supported by cartilage and is of various sizes and shapes in different mammals. It helps in collecting sound waves and it is turned in different direction by the mammals excepting man. Opening of the *external auditory passage* lies at the base of the pinna. The external passage leads up to the *tympanic membrane*. The walls of the passage may be membranous or cartilaginous or osseous in part. The passage is formed of a series of incomplete rings in tachyglossus. The middle ear or tympanic cavity is enclosed by periotic and tympanic bones. The cavity communicates with the pharynx by the eustachian tube. The inner wall of the tympanic cavity bear '*fenestra ovalis* or *fenestra rotunda*. A chain of auditory ossicles —the *malleus*, *incus* and *stapes* run between the tympanic membrane and rotunda. These are the smallest bones in the body and show variation in form. The stapes is with a foramen and the perforation is made by a minute artery as in rabbit. Stapes is rod-shaped in *manis*. The membranous labyrinth of the internal ear is with a specially developed *cochlea*. The cochlea is spirally coiled and is absent in monotremata.

EXCRETORY SYSTEM

The kidney in mammals is metanephric and is the principle excretory organ. There is a pair of kidneys. Each kidney is a compact, bean-shaped structure and is retroperitoneal in position. It is covered over by a connective tissue covering called *capsule*. The median side of each kidney bear a depression called *hilum*. At this point the ureter and renal veins leave the kidney and renal artery and nerve enter the kidney.

The kidney proper is demarked into two distinct regions — an outer *cortex* and an inner *medulla*. The renal corpuscles and convoluted portions of the secretory tubules remain confined in the cortical region. Each renal corpuscle is made up of a *Bowman's capsule* formed by an undented expansion at the cortical end of the excretory tubule. Into the Bowman's capsule lies a capillary bed formed by an artery. The capillary bed is called glomerulus. The wall of the glomerulus is one cell thick. Each tubule, as it leaves the Bowman's capsule becomes differentiated into four distinct regions. They are a *proximal convoluted tubule*, a long *loop of Henle* with *descending* and *ascending* portions and a *distal convoluted tubule*. Secretory tubules with their Bowman's capsules are numerous. It is estimated that there are about 1 million renal corpuscles in each kidney. Each distal convoluted tubule opens in a *collecting tubule*.

The medulla is made up of large area. The area is occupied by a number of *renal pyramids*. Columns of cells called *renal column* of *Bertini* originate from the cortex and invade the spaces in between the renal pyramids. The apex of the pyramids is subdivided into smaller units called lobule. The collecting tubules remain confined usually into the pyramids. The inner border of each pyramid is projected into an out-pocketing of the pelvis. This out-pocketing is called *minor calyx*. Several minor calyces join together and form *major calyces* which in their turn open into the pelvis.

The centre of the kidney is the *sinus* of the metanephros. It is filled up with blood vessels, nerves, fatty tissue, pelvis and calyces. The ureter emerging from the pelvis passes through the hilum and opens into the urinary bladder.

Fluid is removed from the blood by the renal corpuscles and is passed down the secretory and excretory tubule. Most of the filtrate specially glucose and salts (about 99%) is reabsorbed through the walls of the secretory tubule and is returned to the blood stream. The remainder is called urine. Urine is made up of water, urea, sodium chloride, potassium and uric acid. This straw yellow fluid passes down the ureters, remains for some time stored in the urinary bladder and then is voided through the urethra.

The urinary bladder is a muscular sac and is derived from the ventral wall of the cloaca and a portion of allantoic stalk. The ureters open directly on the dorsal posterior side of the bladder in all mammals excepting monotremata.

In many mammals (Proboscidea, cetacea, artiodactyla, etc.) the kidney retains embryonic lobulated condition. In others the kidney surface is smooth in adult stage. In *Procavia* urine is voided as viscid steaks. These animals live in hot and rocky area and as such have developed a mechanism for the retention of as much fluid as possible and as a result the urine is of thick consistency.

REPRODUCTIVE SYSTEM

Male reproductive system. This system consists of a pair of testes, ducts and associated glands. The testes are oval bodies and remain in exceptional cases in their original site of formation in the abdominal cavity. Thus the testes are abdominal in cetacea, elephants, hyracoidea and in some insectivores. In majority of the mammals they pass down the *inguinal canal* and lie in a space between the urinogenital and anal aperture. The space is known as *perinaeum*. The testes may descend down further and may remain inside a pendulus pouch of skin called *scrotum*. The scrotal sac may sometimes be double.

Each testes is covered over by a membrane made up of connective tissue fibre. The membrane are called *tunica albuginea*. Internally the testes are composed of large number of *semeniferous tubules* and *Leydig's* or *interstitial* cells. The Leydig's cells are richly supplied with blood and are located in the interstices between adjacent seminiferous tubules. These cells secrete the male sex hormone. The spermatozoa from each testis is discharged from the seminiferous tubules into a plexiform *rete testis*, from where they go to the epididymis. The epididymis continues as *vas deferens* which runs downwards. At the posterior end the vas deferens bear two swellings. The first swelling is called *ampulla* and the second swelling is called *seminal vesicle* which is glandular. These vesicles do not store seminal fluid but in all probability produce *fructose* to be utilised by the spermatozoa. *Ejaculatory duct* coming out from the vesicle enters into the median urethra and penis.

A small diverticulum called *uterus masculinus* is present at the proximal part of the urethra. The uterus masculinus is in all probability a rudimentary *Müllerian duct*. Surrounding this region lies a large and alveolar *prostrate gland*. It is absent in monotremata, marsupials and cetacea.

Ducts from a pair of small and racemose *Cowper's gland* or *bulbo-urethral glands* open into the urethra near the base of the penis. Both prostrate and Cowper's glands are under nervous and endocrine control and their secretions are added to the spermatozoa.

The structure of penis is variable in different mammals but basically it is composed of sinusoidal and erectile tissue arranged in longitudinal columns. Two such columns on the dorsal side make up the *corpora cavernosa* of penis. These columns are attached proximally to the ischia excepting in monotremes, marsupials and some edentates. A third column of erectile tissue called *corpus spongiosum* occupies a ventral position. It is perforated by the urethra and distally it becomes dilated to form the *glans penis*. An osseous element called *os penis* or *os priapi* is present on the septum between the columns of corpus cavernosa in some rodents, carnivores, bats and some primates. This structure is absent in man and whales. According to some its homologue is the *clitoris* of the female.

At the time of sexual excitement nerve impulses cause dilation of the arterioles and capillaries filling up the sinuses inside the penis. The plain muscles of each sinus wall is now relaxed and contraction of circular muscles occur. Thus the blood flow is impeded causing turgidity and erection of penis. Most of the terrestrial carnivores bear horny spines or *copulatory grapples* near the tip of the penis.

Much experimental work has been done on the mammalian testis and it has now been confirmed that male hormone production is done by the Leydig's cells. The male hormone is called *testosterone*. Synthetic manufacture of testosterone is now possible and any substance having equal physiological properties similar to that of testosterone is called *androgen*.

Castration is a long practice for the improvement of the quality of flesh of domestic animals and to make them docile. A castrated bull is known as *steer*, a castrated horse is called a *gelding*, a castrated boar is called *barrow* and a castrated man is called *eunuch*. If an animal is castrated before puberty, masculine structures and characteristics do not develop. Castration after puberty leads to regression of accesory sex organs but secondary sex characters are little altered. It has been shown that the internal secretion of testes has a profound role on the development of certain parts of skeleton specially the pelvis.

Female reproductive system. It consists of a pair of *ovaries* and a pair of *oviducts*. The ovaries are compact bodies located in the lumbar or pelvic regions. During development they arise at the level of the metanephric kidneys but later descend to their permanent and most posterior location. Mammalian ovaries are small and remain suspended from the middorsal body wall by mesovarium. Blood vessels and nerves enter the ovary at a point called *hilum*. The hilus is attached to the uterus by a *suspensory ligament*. The ovaries are so oriented that the surface is exposed to the coelomic cavity but the funnel of the oviduct lies so close to the ovary that the discharged ovum directly enters into the funnel.

The whole or part of the ovary remain ensheathed by a specialised peritoneal fold called *germinal epithelium*. The ovary is made up of two distinct regions—the outer *cortex* and inner *medulla*. The medullary region is composed of connective tissue, blood and lymphatic vessels, smooth muscles and nerve fibres. The cortex consists chiefly of compact *stroma*. The *Graafian follicles* lie in the cortex. The follicles vary in size according to their states of maturity. Three different types of follicles according to maturity can be recognised. They are *primary*, *growing* and *mature* follicles. Generally primary follicles lie near the ovarian surface, growing ones advance towards the medulla and the mature ones extend throughout the thickness of the cortex and may produce elevations on the ovarian surface.

A primary follicle consists of a centrally located ovum surrounded by a single layer of epithelial *follicular cells*. In growing follicles the follicular cells become arranged in many layers. Each follicle now become surrounded in a sort of capsular arrangement. The cap is called *theca*. The theca is arranged in two layers—the outer layer is called *theca externa*. The cells of the theca externa are long and spindle-shaped. The inner layer of the theca is made up of round cells and is called *theca interna*. It is believed that the cells of the theca interna secrete female sex hormone or *estradiol*. The ovum in a mature follicle ceases to enlarge and becomes surrounded by a clear, thick and transparent envelope. The envelope is produced by the follicular cells and is called *zona pellucida*. The envelope is pierced by minute canals through which nourishing materials enter the ovum. The follicular cells that lie just outside the zona pellucida are columnar in shape, stain differently and appear very conspicuous. They form layer and are known as *corona radiata*. The follicular cells which were solid mass of cells so long now undergo vacuolation and rearrangement. This results in the formation of a cavity called *antrum* or *follicular cavity*. The cavity remains filled up with a semiviscous fluid called *liquor folliculi* or *follicular fluid*. The ovum surrounded by zona pellucida and corona radiata lies on a small hillock of follicular cells and projects into the antrum. The hillock is called *germ hill* or *cumulus oöphorus*. The follicular cells at the periphery are several layer in thickness and is collectively known as *stratum granulosum*.

Many follicles start developing at a time in mammals but most of them degenerate and become *atretic*. In a mature female, at periodic intervals which are typical of each species, one or more follicles grow to maturity, the number being closely related to the number of offsprings produced at a time. Fully developed ovum comes out by rapture of the follicle and comes to the Fallopian tube through the funnel of the oviduct. In cat, rabbit and shrew ovulation does not occurs unless they copulate.

In some mammals the antrum of follicle after the discharge of the ovum becomes filled up with a clot of blood coming from the raptured blood vessels of the theca. Such a body is called *corpus hemorrhagicum*. In other mammals the cells of the stratum granulosum and theca interna undergo transformation. They enlarge and push into the antrum obliterating it. A large and round mass of cells called *corpus luteum* finally fills the antrum. Each corpus luteum persists as a scar-like *corpus albicans*. The corpus luteum acts as important endocrine gland. It secretes a hormone called *Progesterone* which prepares the reproductive tract for pregnancy and for maintenance of pregnancy.

Müllerian or oviducts in paired condition is present in all mammals. In higher mammals the duct is differentiated into three distinct regions. The upper region is called *Fallopian tube*. It is narrow and its free end opens into the coelome forming a fimbricated funnel. The middle part of the duct has become much enlarged to form the *uterus*. The uterus leads to a terminal *vagina* which receives the penis of the male during copulation. The lower part or *neck* of the uterus is called *cervix*.

Fusion of various degrees of the oviducts of two sides occur in mammals. The most primitive condition is present in monotremes. Here the two oviducts remain separate and terminate separately in the urogenital sinus. Each duct is differentiated into anterior narrow Fallopian tube and posterior expanded uterus. The uterus is beset with calcareous glands and the Fallopian tube with albumen glands. It has been seen that in platypus only the left oviduct is functional.

In marsupials oviducts are paired and the two vagina open into a urogenital sinus. In some the vaginae are fused at their anterior ends forming a *vaginal sinus* which extends posteriorly as a blind pocket. This is sometimes called third vagina.

In eutherian mammals a single vagina formed by the fusion of the distal parts of the oviducts is present. The uterine portions of the oviducts show different degrees of fusion resulting different types of uteri. The most primitive type of uterus of eutherian mammals is called *uterus duplex* (Fig. 9.52A) in which the two uteri open separately into the vagina. Uterus duplex is present in many rodents and elephants. The fusion of the two uteri at their lower ends results in the formation of *uterus* *bipartitus* (Fig. 9.52B). Such uterus opens to the vagina by a single aperture. Bipartitus uterus is found in carnivore, pig, cattle, few bats and in some rodents. As a result of still greater degree of fusion the formation of *uterus bicornis* occurs (Fig. 9.52C). Such uterus is found in sheep, whales, insectivores and most bats. Complete fusion of the two uteri has formed *uterus simplex* (Fig. 9.52D). Uterus simplex is present in man and apes.

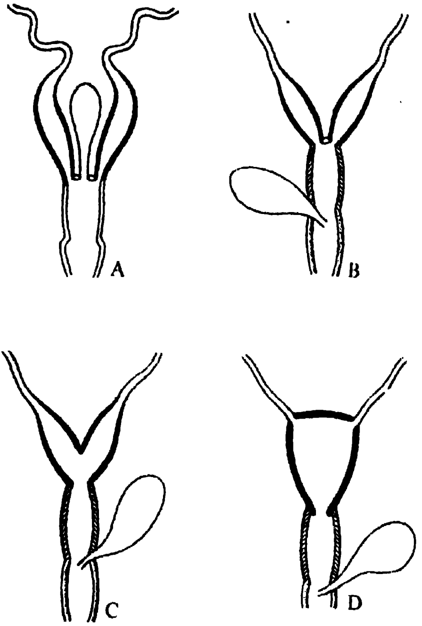

Fig. 9.52. Different types of uterus. A. Uterus duplex. B. Uterus bipartitus. C. Uterus bicornis. D. Uterus simplex.

The external part of the female reproductive organ is called *vulva*. In primates two folds of skin, the *labia minora* are present at the margins of the vestibular opening. In some apes and human female two additional folds called *labia majora* are present at the margins of vulva. They correspond to the scrotal swellings of man.

The glands that are associated with the female genital system are (1) glands of Bartholin, (2) para-urethral glands and (3) vestibular glands. Glands of Bartholin are homologous to the Cowper's gland of males. The gland secretes a clear, viscid fluid under sexual excitement and the fluid acts as lubricant during copulation. Para-urethral glands are homologous to the prostrate glands of males. But the presence of this gland is not constant in all mammals and its function is not known. Vestibular glands are located at the base of urethra and on clitoris. They are mucus secreting glands.

Breeding season. Most mammals breed more or less in specific times of the year. But in man, baboon, giraffe and elephants, no particular

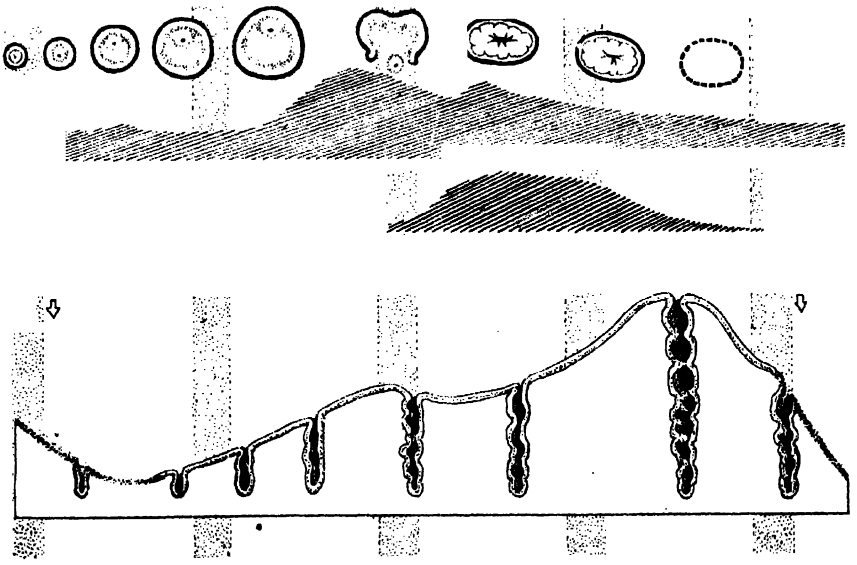

Fig. 9.53. Schematic representation of the events in human menstrual cycle showing the changes in the uterine wall and the interrelationships of different hormones involved.

mating season is present. Animals with a single cycle in each sexual season is called *monoestrus* animals. Dog, koala, kangaroo are examples of monoestrus mammals. *Polyoestrus* mammals are those in which sexual season appears many times a year. Sheep, rat, goat are examples of polyoestrus mammals. Post ovulatory destruction of endometrium results in menstruation. It is present in 'catarrhines', certain primates and African elephant shrew. Fig. 9.53 gives an idea of the relationship between ovary and uterine wall with different hormones in man. The ovaries secrete a hormone called *estrogen*. Estrogen is responsible for the development of secondary sex characters and accessory sex organs of the female. *Progesterone* is another hormone secreted by the *corpora lutea*. Progesterone is concerned with the changes occurring in preparation for and during pregnancy. *Relaxin* is another hormone or hormonal agent. It has been extracted from the corpora lutea of sows, the blood stream of pregnant rabbits, dogs and cows. Whether it is a true ovarian hormone is questionable since the site of its formation is still obscure. Relaxin helps in bringing out formative changes for and during pregnancy.

Experimentally it has been shown that the removal of ovaries before puberty prevents further development of uterus, vagina and Fallopian tube, all of which remain in infantile condition. Extirpitation after puberty brings about atrophy of organs. Removal of ovaries or corpus luteum alone during pregnancy brings about abortion.

SUMMARY

1. Mammals constitute a highly specialised group of vertebrates. Originating from a lowly organised reptilian ancestor during the mesozoic era, mammals have occupied the topmost rank in the evolutionary ladder by virtue of their superorganised brain.

2. A wide variety of forms is encountered amongst mammals which are united together under a class by having diagnostic features. The features are: (*i*) body covered by hairs, (*ii*) presence of sweat and sebaceous glands, (*iii*) presence of mammary glands, (*iv*) 4-chambered heart with only left aortic arch, (*v*) presence of double occipital condyle and seven cervical vertebrae, (*vi*) presence of diaphragm and many others.

3. Classification of class Mammalia is a difficult problem. The living members of the class Mammalia are divided into two subclasses: Prototheria and Theria. Prototheria includes the order *Monotremata*. The subclass theria comprises of two infraclasses—Metatheria and Eutheria. Metatheria has one order *Marsupialia* and the Eutheria consists of 16 living and many extinct orders. Platypus, kangaroos, cats, dogs, apes, man, etc., are some of the examples of the class.

4. Mammals have colonised all environments and show extensive adaptive radiation. Basically they are terrestrial, but due to the stress of existence, have become arboreal, fossorial and even aquatic. Mammals show plantigrade, digitigrade and unguligrade foot postures.

5. Aquatic mammals have undergone extensive modifications and show adaptive convergence with the fishes.

6. The skin is characterised by having hairs and different skin glands which play important role in the physiology of the body. Existence of mammary glands is of paramount importance.

7. The digital tips of mammals have become modified in the form of claws, nails and hoofs. Acquisition of hoof is the monopoly of the ungulates which acts as a shock absorbing pad during movement on hard surface of the earth. Organs of defence in the form of horns and antlers in mammals are worth mentioning, besides the claws and teeth.

8. The digestive system is modified according to food habit. Dentition shows drammatic changes in mammals. Teeth are usually thecodont, diphyodont and heterodont. The cheek teeth have undergone extensive adaptive specialisation.

9. Brain is relatively large and the nervous area is increased by developing convolutions. Presence of corpus callosum is a mammalian characteristic.

10. Parental care has reached the extreme stage of development, particularly in eutherian mammals. Development usually takes place inside the uterus of the mother and the uterii have become modified accordingly.